

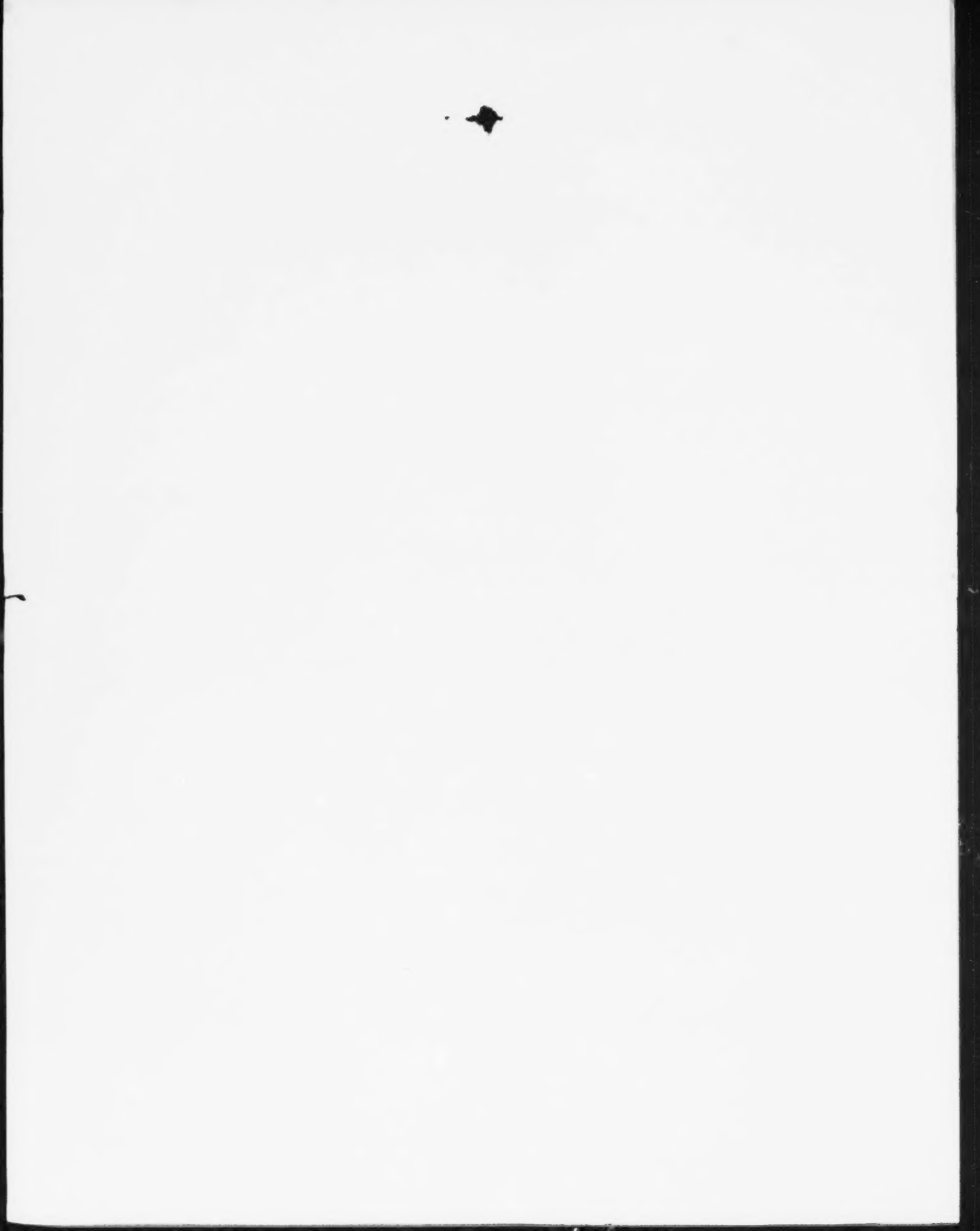
Powertech 

TP 13955E

**DEVELOPMENT OF A TRAILER-MOUNTED
LIGHTWEIGHT CONTAINER MODULE FOR
COMPRESSED GAS VEHICLE FUEL**

Prepared for
Transportation Development Centre
Transport Canada

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Craig Webster, P.Eng.
Powertech Labs Inc.

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This report reflects the views of the authors and not necessarily those of the Transportation Development Centre of Transport Canada or the sponsoring organization.

Un sommaire français se trouve avant la table des matières.



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16. Abstract The lightweight carbon fibre-reinforced high-pressure cylinders developed by Dynetek Industries could be used for the large-volume transportation of compressed hydrogen and natural gas fuels. This report details the development of a lightweight transport unit for compressed fuel gases, and the work involved in preparing an application to the Transport Dangerous Goods Directorate of Transport Canada for a permit. Carbon fibre cylinder designs have never before been used in transportation applications. Work activities included consultation with Transport Canada regarding permit requirements, construction of a demonstration trailer unit at Powertech Labs using lightweight Dynetek cylinders for the transportation of compressed hydrogen fuel, and design qualification testing per Transport Canada requirements on a Dynetek cylinder design. These design qualification tests included hydraulic pressure cycling of cylinders under ambient and extreme temperature conditions, hydraulic burst testing, bonfire testing of pressurized cylinders, and gunfire testing of pressurized cylinders. An application has been prepared for Transport Canada consideration in granting a permit for equivalent level of safety to use the Dynetek carbon fibre cylinder design for transporting compressed hydrogen and compressed natural gas fuels.				
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16. Résumé Les bouteilles haute pression renforcées de fibre de carbone mises au point par Dynetek Industries pourraient servir au transport en grand volume de carburants gazeux, comme l'hydrogène et le gaz naturel comprimé. Le rapport relate les étapes de la mise au point d'un système de stockage léger pour le transport de gaz comprimés, et les travaux préalables à la présentation d'une demande de permis à la Direction générale du transport des marchandises dangereuses de Transports Canada. Car jamais, jusqu'ici, des bouteilles en fibre de carbone n'avaient été utilisées dans des applications de transport. Le projet comportait les tâches suivantes : consultations avec Transports Canada concernant les permis exigés; construction par Powertech Labs d'une remorque porte-tubes de démonstration équipée de bouteilles légères fabriquées par Dynetek pour le transport d'hydrogène comprimé; essais de validation du concept de bouteille Dynetek, menés conformément aux exigences de Transports Canada. Ces essais comprenaient la variation cyclique d'une charge hydraulique dans des conditions de température ambiante et de températures extrêmes, des essais d'éclatement, des essais à la flamme vive et des essais de tir sur des bouteilles sous pression. Une demande de permis de niveau équivalent de sécurité a été déposée auprès de Transports Canada en vue de l'utilisation de la bouteille en fibre de carbone Dynetek pour le transport d'hydrogène comprimé et de gaz naturel comprimé utilisés comme carburants.				
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EXECUTIVE SUMMARY

Advanced lightweight cylinder designs using carbon fibre composite reinforcement have been developed by Dynetek Industries for the high-pressure storage of compressed gases. These designs are currently used on board vehicles for the storage of compressed hydrogen and compressed natural gas as engine fuel. However, these cylinder designs are not yet used for the large-scale transportation of compressed gas fuel, a commodity that is currently only transported in heavy steel tube trailer units of limited capacity.

Transport Dangerous Goods regulations enforced by Transport Canada do not cover the use of carbon fibre-reinforced cylinder designs for transportation purposes; however, Transport Canada has recently issued a Permit for Equivalent Level of Safety to several cylinder manufacturers to use carbon fibre cylinders primarily in air breathing (i.e. class 2.2 dangerous goods) applications. The Dynetek design (model V260) to be used for the transportation of flammable fuel gases is significantly larger than the carbon fibre designs that were granted permits by Transport Canada. In addition, it is intended for the Dynetek design to be used for carrying class 2.1 (flammable) dangerous goods.

To demonstrate the safety of using relatively large carbon fibre cylinders to transport compressed hydrogen fuel, Powertech Labs constructed a small trailer unit using Dynetek cylinders. This unit was used in the U.S. under local approvals to refuel hydrogen vehicles. Powertech also reviewed the performance of Dynetek cylinders used in compressed hydrogen service elsewhere. This information is being used to support the introduction of carbon fibre cylinder designs into relevant Canadian Standards Association (CSA) standards.

Powertech performed design qualification testing of the Dynetek model V260 cylinder design according to Transport Canada requirements. These tests included hydraulic pressure cycling under extreme temperature conditions, bursting, bonfire exposure and gunfire testing. To obtain a permit for equivalent safety from Transport Canada, Dynetek Industries has prepared a design submission using the data provided by Powertech. The design submission addresses how the Dynetek design deviates from the standards requirements and how an equivalent level of safety is maintained. To eliminate the future need for Transport Canada permits of equivalent safety, Powertech has formed a CSA working group to adopt carbon fibre cylinder designs into relevant CSA standards.

SOMMAIRE

Dynetek Industries a mis au point un modèle perfectionné de bouteille légère, renforcée de fibre de carbone pour le stockage haute pression de gaz comprimés. Ces bouteilles sont présentement utilisées à bord des véhicules pour le stockage de carburants gazeux comprimés (hydrogène et gaz naturel). Mais elles ne sont pas encore utilisées pour le transport en grand volume de gaz comprimé. À ce jour, seules des remorques porte-tubes en acier lourd de capacité limitée servent à cette fin.

Le Règlement sur le transport des marchandises dangereuses appliqué par Transports Canada est muet sur l'utilisation de bouteilles renforcées de fibre de carbone à des fins de transport; mais Transports Canada a récemment délivré un permis de niveau équivalent de sécurité à plusieurs fabricants pour que des bouteilles en fibre de carbone puissent servir au stockage d'air comprimé (marchandises dangereuses incluses dans la classe 2.2, Gaz ininflammables). Or, la bouteille de Dynetek (modèle V260) qui servira au transport de carburants gazeux inflammables est beaucoup plus grosse que les bouteilles en fibre de carbone pour lesquelles Transports Canada a délivré des permis. De plus, la bouteille de Dynetek est conçue pour le transport de marchandises dangereuses incluses dans la classe 2.1 (Gaz inflammables).

Pour démontrer qu'il n'est pas dangereux d'utiliser des bouteilles en fibre de carbone relativement grosses pour transporter de l'hydrogène comprimé, Powertech Labs a construit une petite remorque porte-tubes équipée des bouteilles de Dynetek. Cette remorque a été utilisée aux États-Unis, conformément à des approbations locales, pour le ravitaillement de véhicules mus à l'hydrogène. Powertech a également examiné les performances de bouteilles Dynetek utilisées pour le stockage d'hydrogène comprimé dans d'autres applications que le transport. Ces données sont présentement utilisées pour appuyer l'intégration des bouteilles en fibre de carbone au champ d'application des normes pertinentes de l'Association canadienne de normalisation (CSA).

Powertech a réalisé les essais de validation du concept du modèle de bouteille V260 de Dynetek, conformément aux exigences de Transports Canada. Ces essais comprenaient la variation cyclique d'une charge hydraulique dans des conditions de température ambiante et de températures extrêmes, des essais d'éclatement, l'exposition à une flamme vive et des essais de tir sur des bouteilles sous pression. Dans le but d'obtenir un permis de niveau équivalent de sécurité de Transports Canada, Dynetek Industries a préparé un dossier sur son modèle de bouteille V260, en s'appuyant sur les données fournies par Powertech. Le fabricant explique comment, même si sa bouteille ne répond pas aux normes, elle répond quand même au niveau équivalent de sécurité. Pour éviter que Transports Canada ait à étudier d'autres permis de niveau équivalent de sécurité dans l'avenir, Powertech a formé un groupe de travail avec la CSA pour l'intégration des bouteilles en fibre de carbone au champ d'application des normes pertinentes de la CSA.

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1.0 INTRODUCTION

1.1 Background

Increasing interest in the use of hydrogen fuel cell vehicles and natural gas vehicles has resulted in the need to develop a large-scale road transport system for supplying vehicle filling stations with compressed hydrogen and natural gas fuels. Transport Canada regulations for the transportation of dangerous goods currently limits existing compressed gas tube trailer transport designs to the use of steel tubes of thick-walled construction. The road weight (and restricted storage capacity) of steel tube trailers severely limits the economics of transporting compressed gas. In addition, in some areas there are seasonal weight restrictions on roads that prevent the use of heavy steel tube trailers.

The introduction of pressure vessels manufactured using high-strength carbon fibre reinforcement provides an attractive alternative to steel pressure vessels. In addition to providing a significant reduction in the weight-to-volume ratio, carbon fibre also allows significantly higher storage pressures to be used. Because of the high strength of carbon fibre, the wall thickness of these lightweight pressure vessels is significantly less than steel cylinders and thus a greater amount of gas can be stored for a given external volume.

Several tens of thousands of carbon fibre high-pressure compressed gas fuel storage cylinders have been used on board vehicles since 1992. This successful application of lightweight cylinders in road service indicates that this new technology could be safely used as lightweight container units to carry relatively large volumes of compressed gas fuel. For this to come into practice, it is necessary to obtain approval of the carbon fibre design from the Transport Dangerous Directorate of Transport Canada.

The concept of using composite-reinforced cylinders for the large-scale transportation of compressed gas was recently introduced in Germany. Mannesmann Cylinder Systems received approval from the Technischer Ueberwachungsverein (the German safety and standards institution) for cylinder trailers composed of steel cylinder liners hoop-wrapped with Kevlar composite reinforcement. These road trailers are currently being used in Germany for the transportation of compressed hydrogen.

1.2 Dynetek Industries

Dynetek Industries Ltd. of Calgary, Alberta is a world leader in the design and manufacture of lightweight carbon fibre-reinforced cylinders. Dynetek supplies most automotive manufacturers worldwide with compressed gas fuel storage cylinders for natural gas vehicles and prototype hydrogen fuel cell vehicles. The Dynetek design comprises a thin aluminum alloy liner that is fully wrapped with carbon fibre

reinforcement. Dynetek manufactures cylinders up to 3 m long, up to 610 mm in diameter, and with water capacities up to 350 L.

Dynetek cylinder designs are registered in Canada under the Canadian Standards Association (CSA) B51 standard for compressed natural gas use. The CSA B51 standard covers the requirements for cylinders used for compressed natural gas service on board vehicles and for stationary ground storage. Dynetek designs are also registered in British Columbia for compressed hydrogen service, using the CSA B51 standard as a reference.

1.3 Regulatory Requirements

The transportation of compressed gases not used on board a vehicle as an engine fuel is covered by Transport Dangerous Goods regulations. The Transport Dangerous Goods Directorate of Transport Canada is responsible for enforcing regulations covering compressed gases that may be transported across provincial borders.

The requirements for transporting compressed gases are described in the CSA B340 standard "Selection and Use of Cylinders, Spheres, Tubes, and Other Containers for the Transportation of Dangerous Goods, Class 2". The design specifications for the pressure vessels listed in CSA B340 are detailed in the CSA B339 standard "Cylinders, Spheres, and Tubes for the Transportation of Dangerous Goods".

While the CSA B339 standard includes specifications for composite-reinforced cylinder designs, these composites are limited to the use of glass fibres. CSA B339 has no provision for cylinder designs that use carbon fibre reinforcement simply because this is a relatively new material compared to fibreglass. The TC-3FCM cylinder specification in the CSA B339 standard most closely describes the Dynetek design, except that the specification only allows for glass fibre composite reinforcement, not carbon fibre. In addition, the TC-3FCM specification has the following limits:

- Clause 9.1.1 specifies a maximum water capacity of 91 L, and a service pressure up to 34.5 MPa.
- Clause 4.2.6 specifies that TC-3FCM composite containers shall be used only for gases in Classification 2.2, or compressed natural gas.

Despite the absence of carbon fibre specifications in the CSA B339 standard, the Transport Dangerous Goods Directorate may issue permits for an equivalent level of safety. This requires the applicant to demonstrate - using drawings, plans, calculations, procedures, and test results - how the proposed manner of transport will "ensure a level of safety at least equivalent to that achieved by complying with the Regulations". The following manufacturers have received from Transport Canada a Permit for Equivalent Level of Safety for their carbon fibre cylinder designs in general accordance with the TC-3FCM specification:

- Structural Composites Industries for transporting Class 2.2 (inert) gases.
- Luxfer Gas Cylinders for transporting Class 2.2 (inert) gases.

However, an application by Dynetek Industries to Transport Canada for a Permit for Equivalent Level of Safety for a carbon fibre-reinforced cylinder design must also consider the following additional restrictions in the CSA B340 standard for transporting compressed hydrogen:

- Clause 5.2.1 specifies that compressed hydrogen can only be filled in certain cylinder designs of either steel or aluminum construction.
- Clause 5.2.2.2 specifies that compressed hydrogen can only be filled in tubes of certain steel designs.
- Clause 4.6.2 specifies that cylinders of composite construction can only be used to transport classification 2.2 (non-flammable) gases or compressed natural gas - this classification prevents the use of TC-3FCM specification cylinder designs for compressed hydrogen transportation.

It is therefore necessary to demonstrate the safety of using large-volume carbon fibre-reinforced cylinder designs for the transportation of compressed hydrogen and natural gas fuels.

2.0 APPROACH

Dynetek has been funded under a separate contract through Natural Resources Canada to construct a trailer unit for the transportation of compressed natural gas fuel. This trailer unit would then be used as the basis for demonstrating the safety of using lightweight cylinder designs for the transportation of compressed fuel gases. Each of the three separate container units mounted on the trailer will be composed of 39 large-volume lightweight cylinders of 230 bar working pressure (see Figure 1). Each model V260 lightweight cylinder will have a water volume of 260 L, and will measure 381 mm in diameter by 2,800 mm in length. The completed trailer with the three container units will consist of a total of 117 cylinders, providing a storage capacity of 30,420 L (water volume).

For this project, Powertech was to perform the necessary design work on the trailer to ensure compliance with the regulatory requirements for a Transport Canada permit; however, delays in initiating the Natural Resources Canada contract has caused the trailer unit construction at Dynetek to be significantly behind the schedule of this project. As a result, a lightweight trailer design was constructed at Powertech using Dynetek cylinders for the transportation of compressed hydrogen. The trailer is being used to provide service experience with carbon fibre-reinforced cylinders for the transportation of compressed gas fuels.

Powertech efforts in this project focused on supporting the development of a design submission by Dynetek to Transport Canada for a permit to use the carbon fibre reinforced cylinder designs. This support was provided in the following activities:

- Consultation with regulatory authorities regarding the requirements for demonstrating that carbon fibre designs could provide a level of safety equivalent to cylinder designs already specified in standards.
- Working with the Canadian Standards Association to update existing standards regarding the use of carbon fibre cylinders.
- Testing the condition of Dynetek cylinders that have been used in compressed hydrogen service for several years.
- Collecting experience operating the Powertech lightweight trailer unit for the transportation of compressed hydrogen.
- Performing design qualification testing of the Dynetek V260 design to the CSA B339 TC-3FCM specification for Transport Canada.

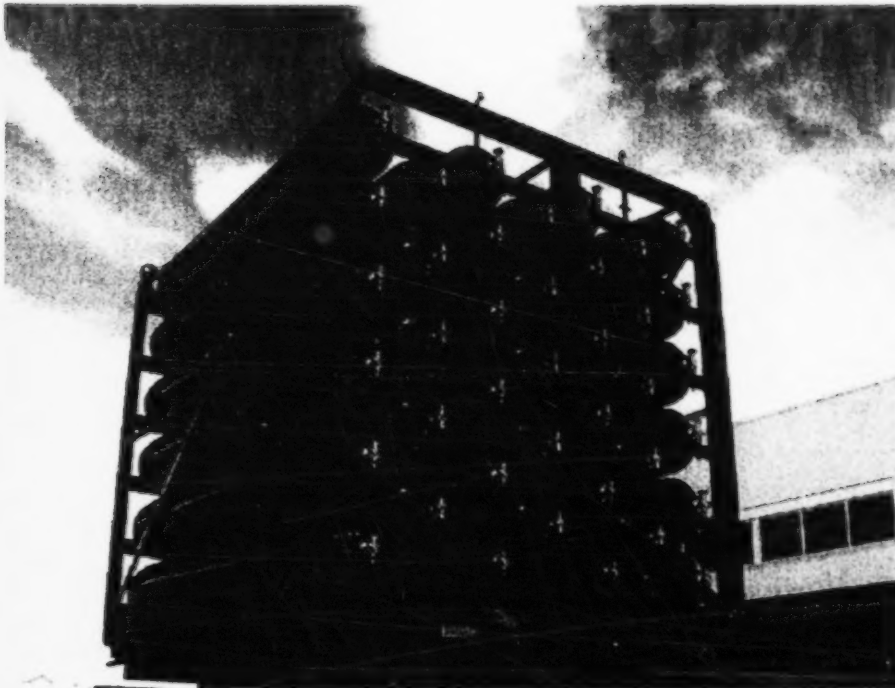


Figure 1 Completed Dynetek container unit for Natural Resources Canada



Figure 2 Schematic of three Dynetek container units mounted on a trailer

3.0 WORK PROGRAM

3.1 Information Gathering

Discussions were held with Transport Canada personnel to determine the requirements for the approval of lightweight carbon fibre cylinder designs for transportation uses.

Transport Canada Transport Dangerous Goods personnel stated that if the Dynetek design application duplicated the design requirements of previous carbon fibre cylinder design applications by other manufacturers, such as SCI and Luxfer, that had received a Permit for Equivalent Level of Safety, then there would be no problem in Dynetek also receiving approval. However, if the design varied from designs that had been previously provided with a Permit, then an argument would have to be presented to justify why the design differences would still provide an equivalent level of safety. The typical timing for approval is three to four months, provided the application duplicates the requirements of previous applicants who have already received permits [1].

Discussions were also held with Transport Canada Transport Dangerous Goods personnel regarding permissible deviations in the design qualification test requirements listed in the TC-3FCM specification in the CSA B339 standard for the Dynetek design. These deviations were necessary due to the fact that the Dynetek design exceeded the size limits for the TC-3FCM specification, thus changing several test parameters. It was determined that changes in the test procedures could be accepted, provided that a rationale was provided to explain how an equivalent level of safety was achieved by the changes [1].

Transport Canada Transport Dangerous Goods advised that to expedite approval, it would be preferable to issue a permit rather than wait for the CSA standards to be changed and then recognized by Transport Canada regulations. It was also advised that the carbon fibre design type should be introduced to the relevant CSA committee at the same time to initiate inclusion into the CSA B339 standard, thus removing any future requirement to apply for a permit to approve a carbon fibre cylinder design [2].

The Transport Canada Road Safety Directorate said that while Transport Dangerous Goods is responsible for enforcing hazardous materials regulations, it was the responsibility of this group to ensure the road safety and the load rating of the trailer unit [3].

Following the advice of Transport Canada, contact was established with the CSA and Powertech became a member of the CSA B339/340 standards group. A CSA B339/340 meeting in Toronto in March 2001 was attended by Powertech. At that meeting, a CSA Working Group was formed, with Powertech as the Chair, to consider the introduction of carbon fibre cylinder designs into the standard.

3.2 Technical Support on Detailed Design

Initially, efforts concentrated on developing a trailer structure for supporting the Dynetek cylinders that would provide equivalent safety to existing steel tube trailer designs. Clause 4.5 of the CSA B340-00 standard has several specific requirements for steel tube trailer designs. Because of their wall thickness and strength, steel tubes are typically installed in an exposed position on transport trailers. For the lightweight container trailer design, it was proposed that multiple cylinders be manifolded together within a protective frame or container. This container module could then be placed in an enclosed transport trailer unit for transportation. The protective framework, combined with the transport trailer covering, would provide the necessary protection from collision damage.

Upon careful review of the CSA B340-00 standard, however, it was determined that the definition of a "tube" was a container with a water capacity greater than 450 L. A "cylinder" is defined as having a water capacity of less than 450 L. The Dynetek cylinders have a water capacity of 260 L. As a result, the specific requirements under clause 4.5 for tubes attached to trailers would not apply to Dynetek, since it has cylinders and not tubes. Instead, it is believed that the Dynetek design would fall under clause 4.4 for "Manifolded Containers". The only structural requirement for manifolded containers is for the cylinders to be "...supported and held together as a unit by structurally adequate means". There are also the following additional requirements for manifolded containers of compressed gas:

- Valves and pressure relief devices (PRDs) must be protected from impact.
- Each container shall be equipped with a PRD.
- PRDs on horizontal cylinders filled with Class 2.1 (flammable) gas shall vent upwards.
- Each cylinder shall have a shut-off valve.

In accordance with the above requirements for a manifolded container unit, a demonstration trailer was constructed at Powertech Labs using internal funding. It consisted of a manifolded container of 16 Dynetek model W292 carbon fibre cylinders mounted in a protective structural framework of steel. The manifolded container was then mounted on a trailer to make it transportable (see Figure 3). The unit was designed for the transportation of compressed hydrogen at 250 bar. To date, it has only been used in the United States under local approvals for fuel hydrogen vehicles involved in a rally from Los Angeles to Las Vegas (see Figure 4).

One of the purposes of the trailer unit was to demonstrate that carbon fibre cylinder designs could be safely used to transport compressed hydrogen. The trailer unit also demonstrated that significant quantities of compressed gas fuel could be transported in a lightweight package that could be towed by a light-duty vehicle. The trailer can carry 82 kg of hydrogen with a trailer weight of just over 4,000 kg. This compares favourably to a steel tube trailer unit that has 10 times the road weight and only 3 times the hydrogen capacity.

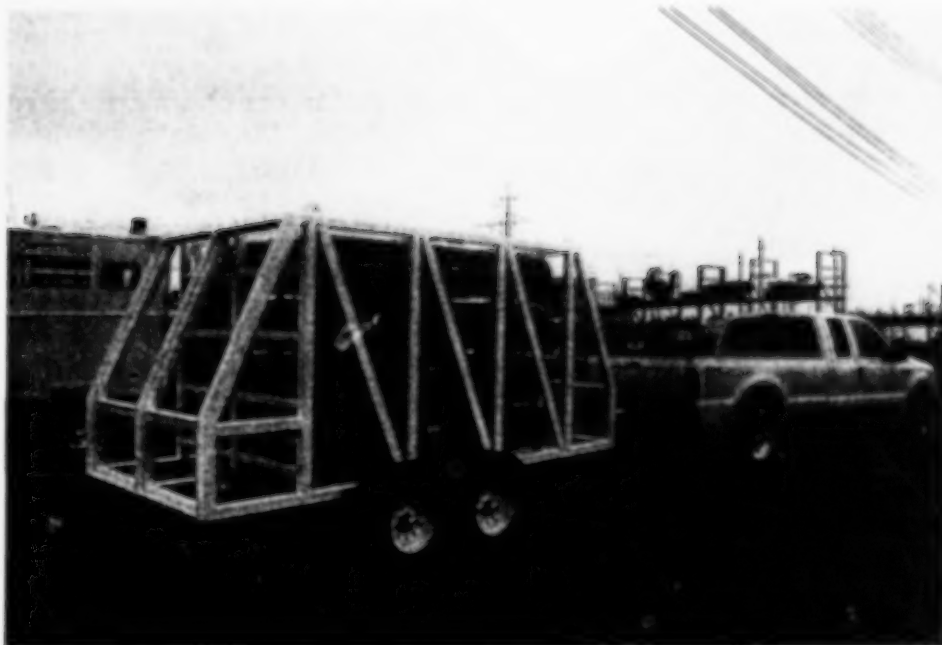


Figure 3 Support framework for transportable container unit of Dynetek cylinders



Figure 4 Complete transportable container unit being used to refuel a fuel cell vehicle

3.3 Permit to Use Dynetek Cylinder Design for Compressed Hydrogen

Currently, the CSA B340-00 standard does not allow the use of type TC-3FCM cylinder designs to carry hydrogen. Type TC-3FCM designs are, however, allowed to carry natural gas, which is a flammable gas with very similar properties to hydrogen. It is therefore necessary to get the CSA B340 standard to recognize that type TC-3FCM designs can also be used to safely transport compressed hydrogen.

The CSA Working Group formed by Powertech to address the issues involving the introduction of carbon fibre cylinder designs into the CSA B339/B340 standards will also address the issue of using TC-3FCM specification designs to transport compressed hydrogen.

While changes to the standards are being pursued, Dynetek has prepared a design application to Transport Canada for a Permit for Equivalent Level of Safety to use the carbon fibre reinforced cylinder design for the transportation of compressed hydrogen and compressed natural gas fuels.

3.4 Performance of Tests

Discussions with Transport Canada indicated that the Dynetek cylinder design, and not the entire trailer unit, would require a permit from Transport Canada. As a result, the performance tests portion of this project focused on the qualification testing of the Dynetek cylinder design in accordance with the CSA B339 standard for a TC-3FCM specification design. All design qualification tests were performed at Powertech Labs and observed by an authorized inspector from Arrowhead Inspection representing Transport Canada.

Originally, the proposal was to perform design qualification tests on a Dynetek model W292 cylinder design. However, the Dynetek trailer design was changed to meet Natural Resources Canada specifications and the cylinder design was changed to a model V260. The following tests were therefore conducted on the V260 model per clause 9.2 of the CSA B339 standard:

- Ambient temperature cycling test of two cylinders per clause 9.13.3(a).
- Environmental cycling test of two cylinders per clause 9.13.3(b).
- Burst test of two cylinders per clause 9.13.4.
- Gunfire test of one cylinder per clause 9.13.5.
- Bonfire test of two cylinders per clause 9.13.6.

The test reports are included in Appendix A.

3.5 Permit to Operate in Canada

Dynetek is in the process of preparing an application to the Transport Dangerous Goods Directorate of Transport Canada for a permit to use the Dynetek design under the TC-3FCM specification for transporting compressed hydrogen and compressed natural gas. The application requires an explanation for deviations from the CSA B339 and B340 standard, including:

- Use of the design for transporting compressed hydrogen.
- Use of carbon fibre composite reinforcement.
- Design exceeding 91 L limit.
- The fact that bonfire testing could not be performed in the vertical position due to the length of the oversize design.

The application will include a description of the successful use of the Dynetek design in compressed hydrogen and compressed natural gas service, and the use of the Powertech demonstration trailer for fuelling hydrogen vehicles.

4B CONCLUSION

The operation of the Powertech lightweight trailer unit, the review of cylinders removed from compressed hydrogen service, and the performance of thousands of Dynetek cylinders in compressed natural gas vehicle service worldwide have demonstrated that the Dynetek carbon fibre-reinforced cylinder design is suited for the transportation of compressed fuel gas. This conclusion is further reinforced by the fact that the Dynetek design successfully completed design qualification testing in general accordance with the requirements for a TC-3FCM specification design in the CSA B339 standard.

5.0 RECOMMENDATION

The development of compressed gas fuel types should be promoted by supporting the updating of standards to recognize advances in technologies that improve the economics of using alternative fuels.

REFERENCES

1. Discussions with Amy Park, Senior Specialist – Cylinders, Transport Dangerous Goods, Transport Canada
2. Discussion with Doug Dibble, Chief – Research and Governmental Activities, Transport Dangerous Goods, Transport Canada
3. Discussion with Dan Davis, Chief – Standards and Regulations, Road Safety Directorate, Transport Canada

APPENDIX A

CSA B339 TEST REPORTS

TEST REPORT

CSA B339-96 (9.13.5) GUNFIRE TEST

Prepared for: Dynetek Industries Ltd.

Project Number: 12670-36

Manufacturer: Dynetek Industries Ltd.
Part Type: V260TDG223G5N
Serial Number: H3223
Part Data: Type-3 Cylinder, 223 bar (3240 psi) Service Pressure

TEST CONDUCTED:

The following test was conducted in accordance with:

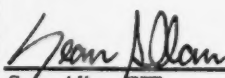
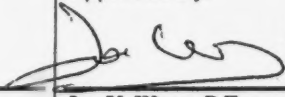
- CSA B339-96, Clause 9.13.5: Gunfire Test

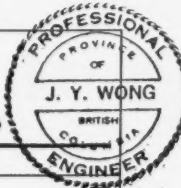
TEST PROCEDURE:

One representative cylinder, filled with air or nitrogen to service pressure, shall be impacted by a 7.5 mm calibre armour-piercing projectile having a velocity of approximately 850 m/s. The cylinder shall be so positioned that the projectile impact is in the cylinder sidewall wrapping at approximately a 45° angle and aimed to exit at the cylinder sidewall. The distance from the firing location to the test cylinder shall not exceed 45 m. The tested cylinder shall reveal no evidence of a fragmentation failure. The approximate size of entrance and exit openings shall be recorded.

TEST RESULTS:

One cylinder was tested according to the above criteria and exhibited no evidence of fragmentation failure.

Tested By:  Sean Allan, EIT	Approved By:  Joe Y. Wong, P.Eng
Date: August 12, 2002	



TEST REPORT

CSA B339-96 (9.13.6) BONFIRE TESTS

Prepared for: Dynetek Industries Ltd.

Project Number: 12670-36

Manufacturer: Dynetek Industries Ltd.
Part Type: V260TDG223G5N
Serial Number: H3226, H1033
Part Data: Type-3 Cylinder, 223 bar (3240 psi) Service Pressure
VTI Valve and PRD

TEST CONDUCTED:

The following test was conducted in accordance with:

- CSA B339-96, Clause 9.13.6: Bonfire Test

TEST PROCEDURE:

The test was performed in general accordance with Clause 9.13.6 (Bonfire Tests) of the CAN/CSA-B339-96 standard. One finished cylinder was provided for the bonfire test. The cylinder was charged to 223 bar (70°F) with Compressed Natural Gas. The cylinder was placed above a burner apparatus capable of enveloping the cylinder system in an environment having a temperature of approximately 648°C in 5 minutes. Four thermocouples were positioned on the cylinder: one on the PRD, a second midway along the cylinder, a third midway along the cylinder, and a final fourth thermocouple on the tail end of the cylinder. A schematic of the test setup is shown in Figure 1. The thermocouple temperatures (Figures 3, 8) and container pressure (Figures 2, 7) were recorded during the test.

The cylinder was then burst hydrostatically (Figures 4, 9).

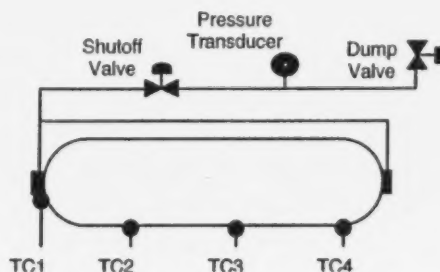


Figure 1: Bonfire Schematic

TEST RESULTS:

Cylinder H3226

The pressure relief device activated after 100 seconds without cylinder failure. The bonfire test pressure and temperature data is appended. The cylinder ruptured at a pressure recorded to be 813.6 bar (11,800 psi).

TEST REPORT

CSA B339-96 (9.13.6) BONFIRE TESTS

Bonfire Pressure Data
Dynetek Cylinder#: H3226

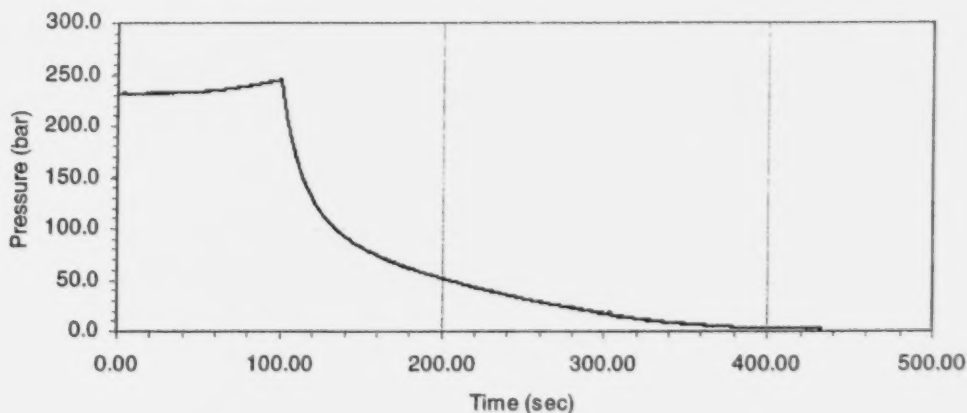


Figure 2: Dynetek H3226, Bonfire pressure plot

Bonfire Temperature Data
Dynetek Cylinder#: H3226

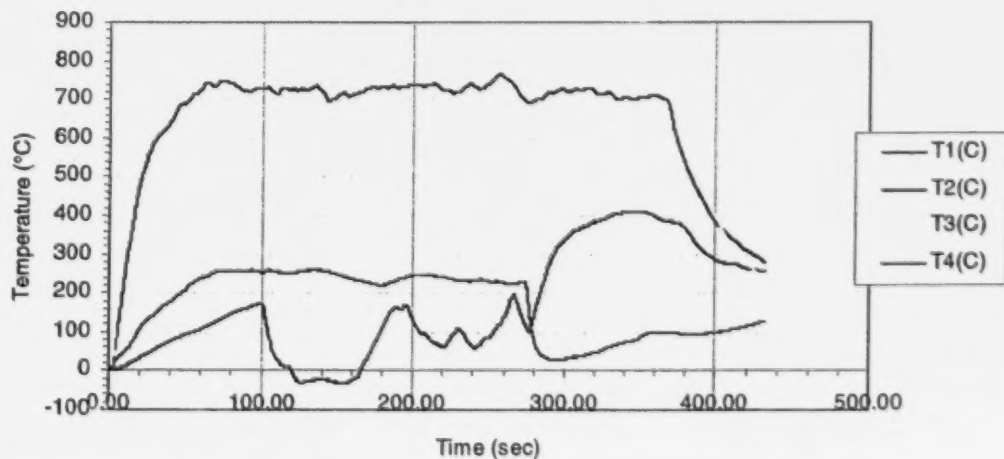


Figure 3: Dynetek H3226, Bonfire temperature plot

CSA B339-96 (9.13.6) BONFIRE TESTS

DYN-H3226 Bonfire Burst

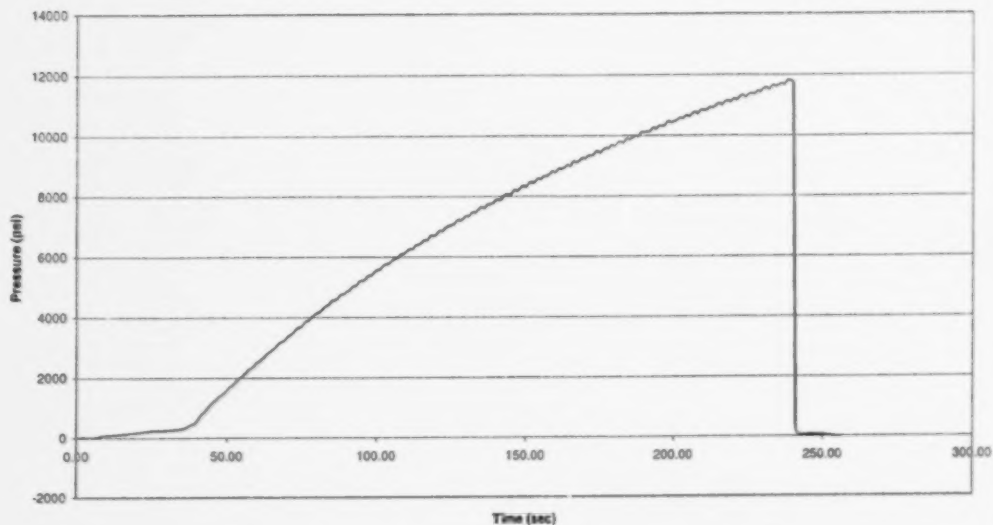


Figure 4: Dynetek H3226, Hydrostatic burst pressure plot

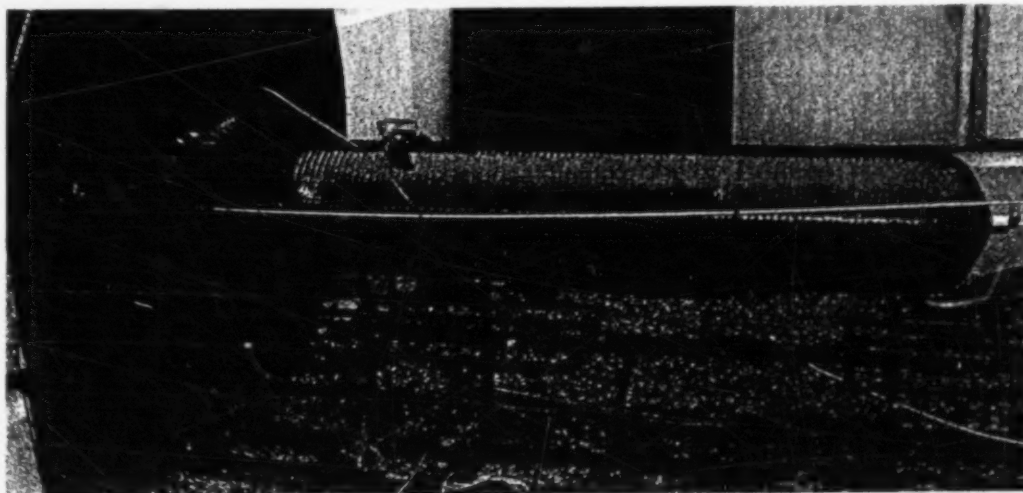


Figure 5: Dynetek H3226, Image of cylinder bonfire apparatus

CSA B339-96 (9.13.6) BONFIRE TESTS



Figure 6: Dynetek H3226, Image of cylinder after burst

Cylinder H1033

The pressure relief device activated after 53 seconds without cylinder failure. The bonfire test pressure and temperature data is appended. The cylinder leaked at the neck at a pressure recorded to be 712.9 bar (10,340 psi).

TEST REPORT

CSA B339-96 (9.13.6) BONFIRE TESTS

Bonfire Pressure Data
Dynetek Cylinder#: H1033

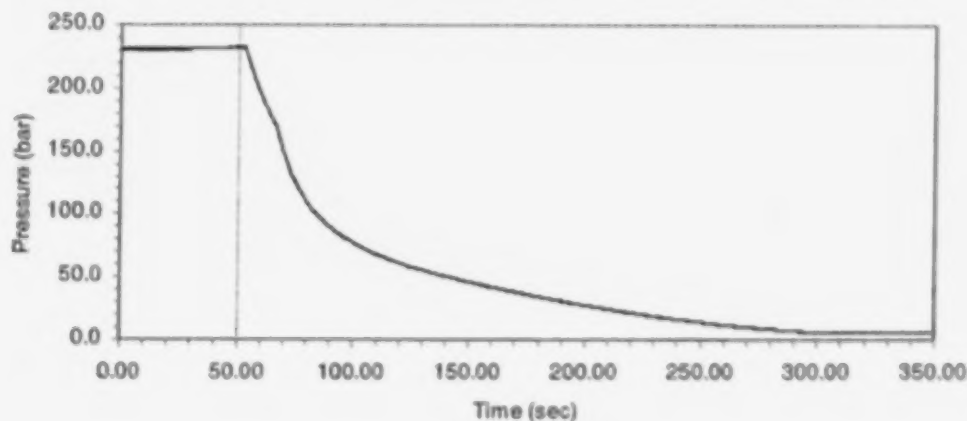


Figure 7: Dynetek H1033, Bonfire pressure plot

Bonfire Temperature Data
Dynetek Cylinder#: H1033

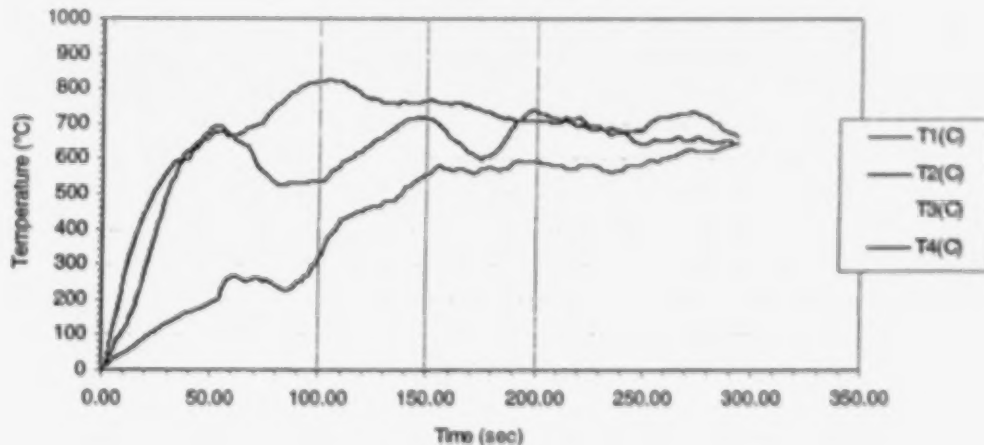


Figure 8: Dynetek H1033, Bonfire temperature plot

CSA B339-96 (9.13.6) BONFIRE TESTS

DYN-H1033 Bonfire Burst

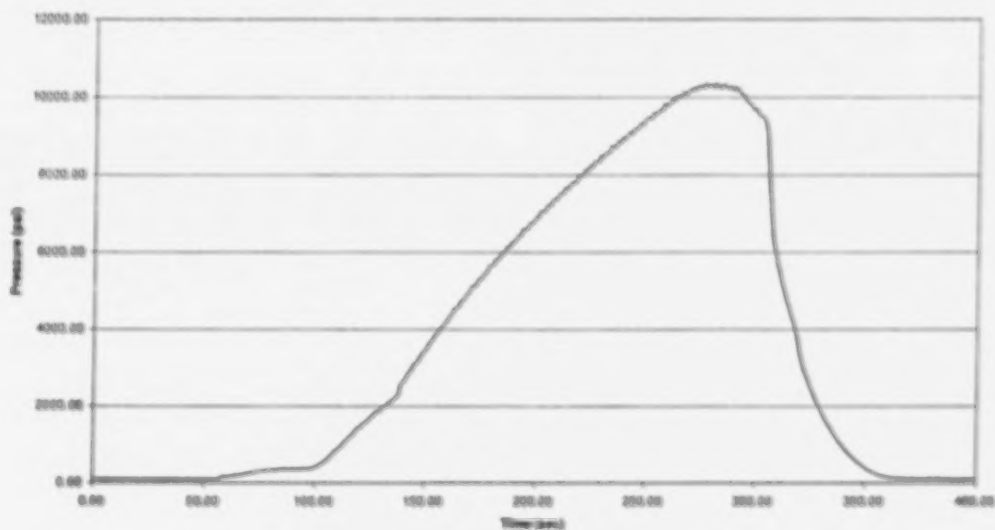


Figure 9: Dynetek H1033, Hydrostatic burst pressure plot

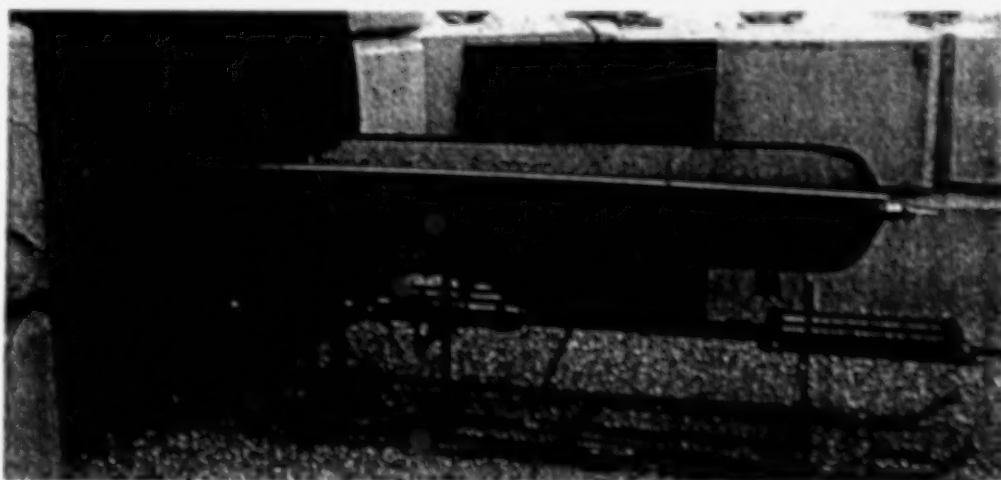


Figure 10: Dynetek H1033, Image of cylinder bonfire apparatus

TEST REPORT

CSA B339-96 (9.13.6) BONFIRE TESTS

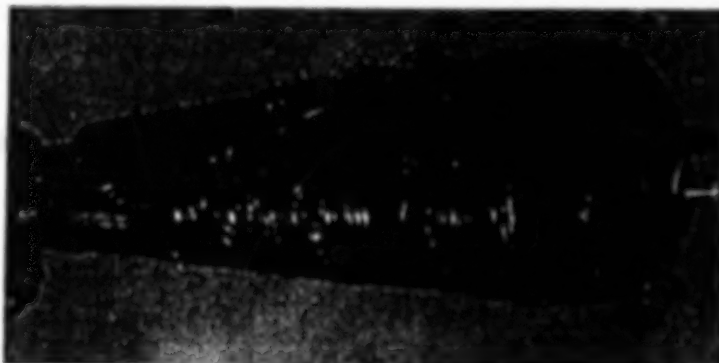


Figure 11a: Dynetek H1033, Image of cylinder after burst

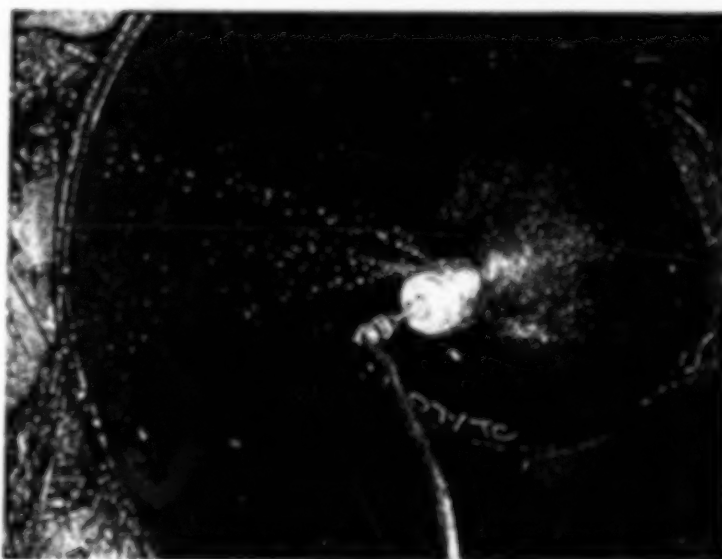
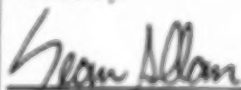


Figure 11b: Dynetek H1033, Image of cylinder during leaking

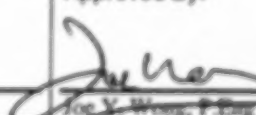
Tested By:



Sean Allan, EIT

Date: August 12, 2002

Approved By:



J. Y. Wong, P. Eng



TEST REPORT



CSA B339-96 (9.13.3) CYCLING TESTS

Prepared for: Dynetek Industries Ltd.

Project Number: 12670-36

Manufacturer: Dynetek Industries Ltd.
Part Type: V260TDG223035N
Serial Number: H1034, H1024, H3217, H3212
Part Data: Type-3 Cylinder, 223 bar (3240 psi) Service Pressure

TEST CONDUCTED:

The following test was conducted in accordance with:

- CSA B339-96, Clause 9.13.3 (a): Ambient Temperature Cycling Test
- CSA B339-96, Clause 9.13.3 (b): Environmental Cycling Test

TEST PROCEDURE:

Cycling tests shall be performed hydrostatically at a rate not exceeding 4 cycles /min from approximately 0 kPa to the specified pressure. Testing shall be as follows:

- a) Ambient temperature cycling test. One cylinder shall be cycling tested at ambient temperature with out failure
 - (i) to service pressure to 10 000 cycles, and (Figures 1, 5)
 - (ii) to 1.11 times test pressure for 30 cycles (Figures 2, 6)
- b) Environmental cycling test. One cylinder free of any protective coating, shall be tested in accordance with the following sequence without distortion, deterioration, or failure:
 - (i) conditioning for 48 h, without pressure, at 60° C or higher at 95% or greater relative humidity;
 - (ii) cycling testing to service pressure for 5 000 cycles under the same condition; (Figures 9, 10, 16, 17)
 - (iii) stabilization without pressure at ambient conditions;
 - (iv) cycling testing to service pressure for 5 000 cycles at -50° C or lower; (Figures 11, 12, 18, 19)
 - (v) stabilization without pressure at ambient conditions;
 - (vi) cycle testing to 1.11 times test pressure for 30 cycles at ambient temperature (Figures 13, 20).
- c) The cylinder shall then be tested hydrostatically to destruction and the burst pressure recorded. Figures (3, 7, 14, 21)

TEST RESULTS:

Though only one cylinder is required, data from two cylinders are provided.

Cylinder H1034

The cylinder showed no signs of visually observable damage, distortion, or leakage after completion of pressure cycling.

The cylinder leaked at a recorded pressure of 857.7 bar (12,440 psi).

TEST REPORT

CSA B339-06 (9.13.3) CYCLING TESTS

0196-H1034 Ambient Cycling Test
10,000 cycles High/Low Pressure Plot

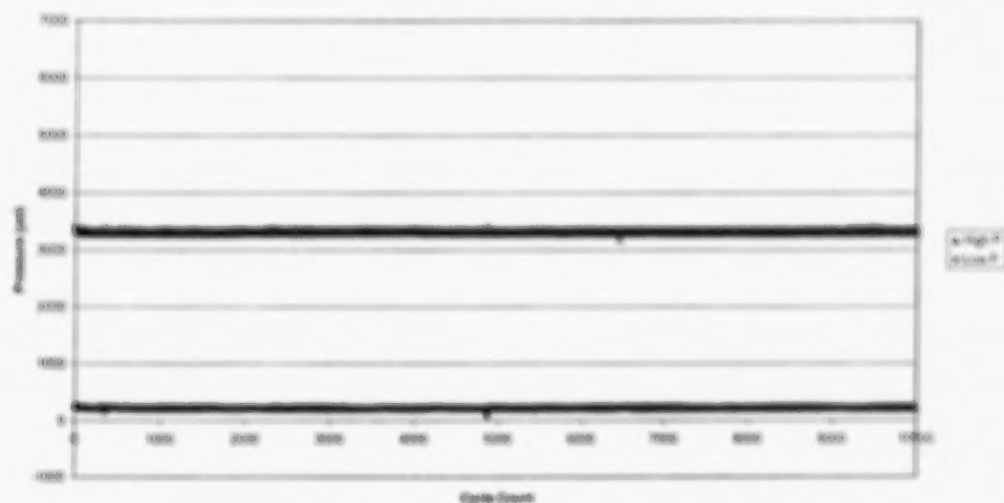


Figure 1: Dynatech H1034, Plot of High and Low pressure values for 10,000 cycles

0196-H1034 Ambient Cycling Test
50 cycles High/Low Pressure Plot

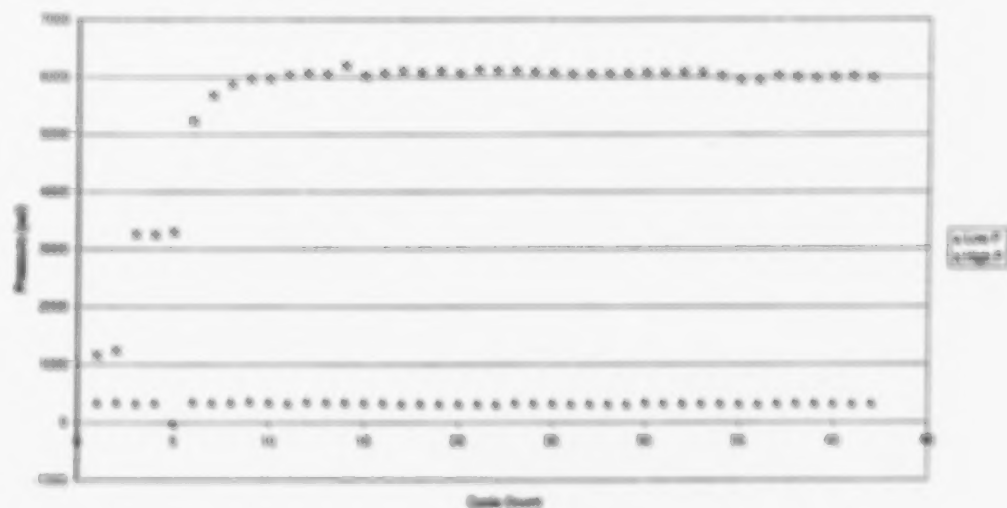


Figure 2: Dynatech H1034, Plot of High and Low pressure values for 50 cycles

TEST REPORT

CSA B339-96 (9.13.3) CYCLING TESTS

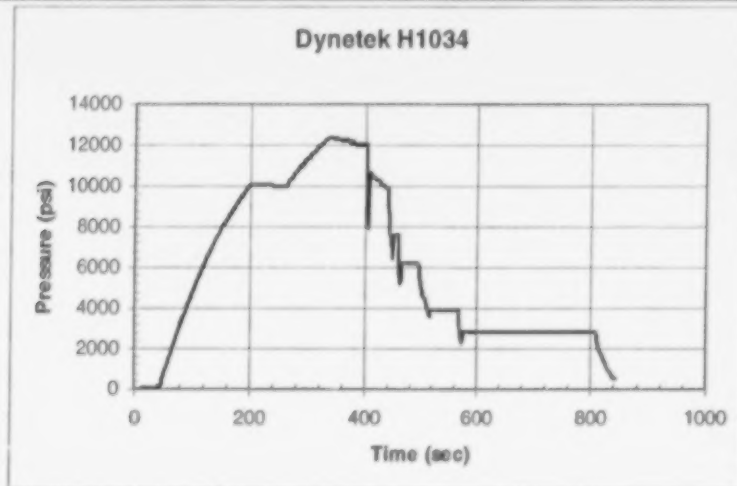


Figure 3: Dynetek H1034, Plot of burst pressure



Figure 4: Dynetek H1034, cylinder after rupture

Cylinder H1024

The cylinder showed no signs of visually observable damage, distortion, or leakage after completion of pressure cycling.

The cylinder ruptured at a recorded pressure of 731.7 bar (10,612 psi).

TEST REPORT

CSA B339-96 (9.13.3) CYCLING TESTS

DYN-H1024 Ambient Cycling Test
10,000 cycles High/Low Pressure Plot

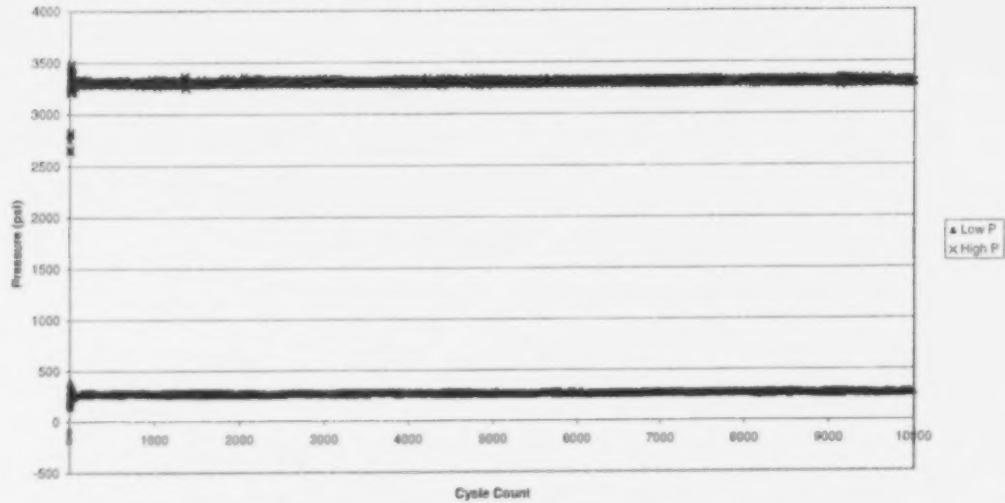


Figure 5: Dynetek H1024, Plot of High and Low pressure values for 10,000 cycles

DYN-H1024 Ambient Cycling Test
30 cycles High/Low Pressure Plot

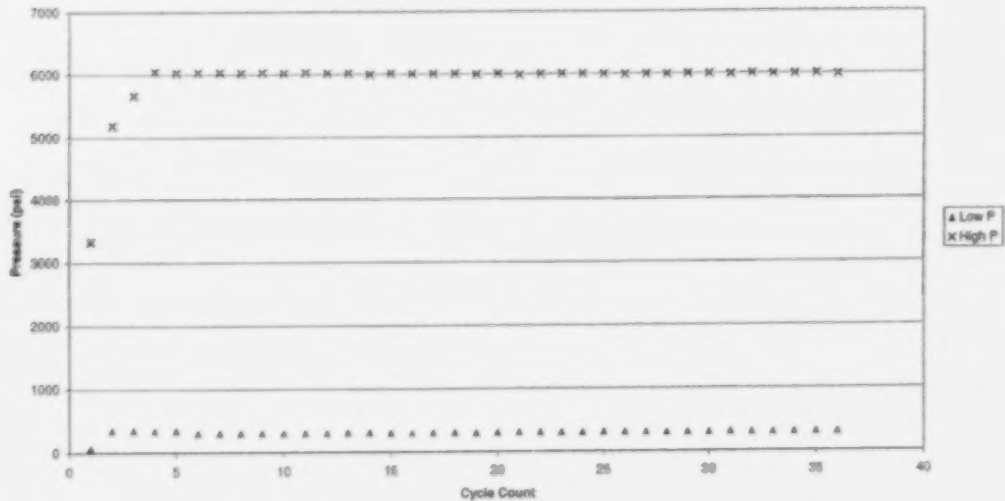


Figure 6: Dynetek H1024, Plot of High and Low pressure values for 30 cycles

TEST REPORT

CSA B339-96 (9.13.3) CYCLING TESTS

Dynetek H1024

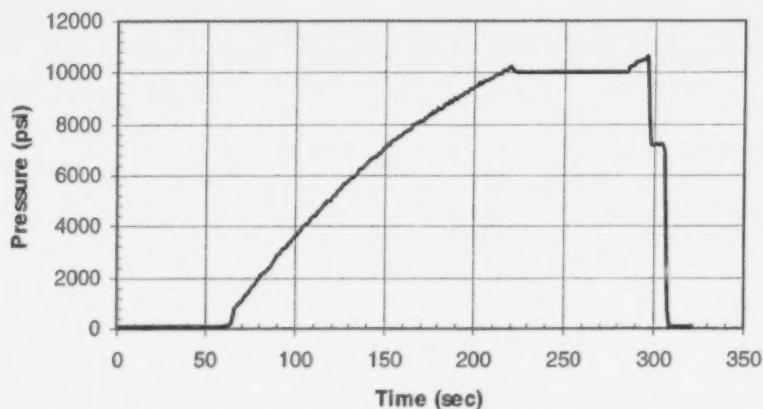


Figure 7: Dynetek H1024, Plot of burst pressure

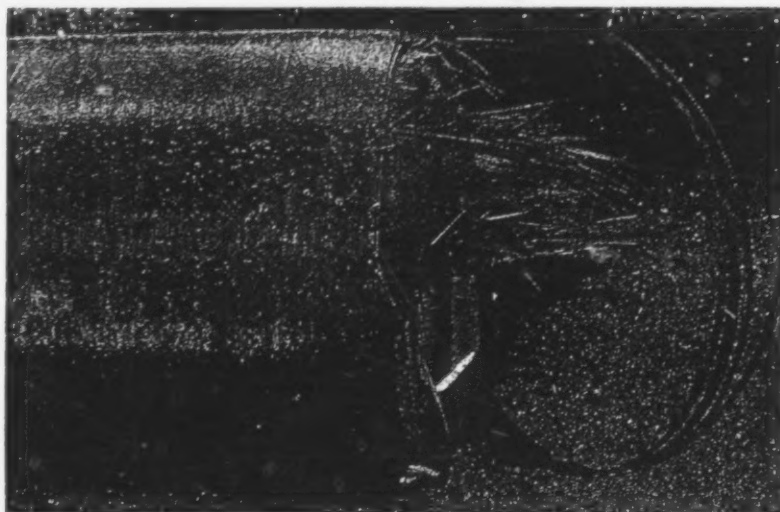


Figure 8: Dynetek H1024, cylinder after rupture

Cylinder H3217

The cylinder showed no signs of visually observable damage, distortion, or leakage after completion of pressure cycling.

The cylinder ruptured at a recorded pressure of 889.4 bar (12,900 psi).

CSA B339-96 (9.13.3) CYCLING TESTS

DYN-H3217 Environmental Cycling
5,000 cycles (Hot) High/Low Pressure Plot

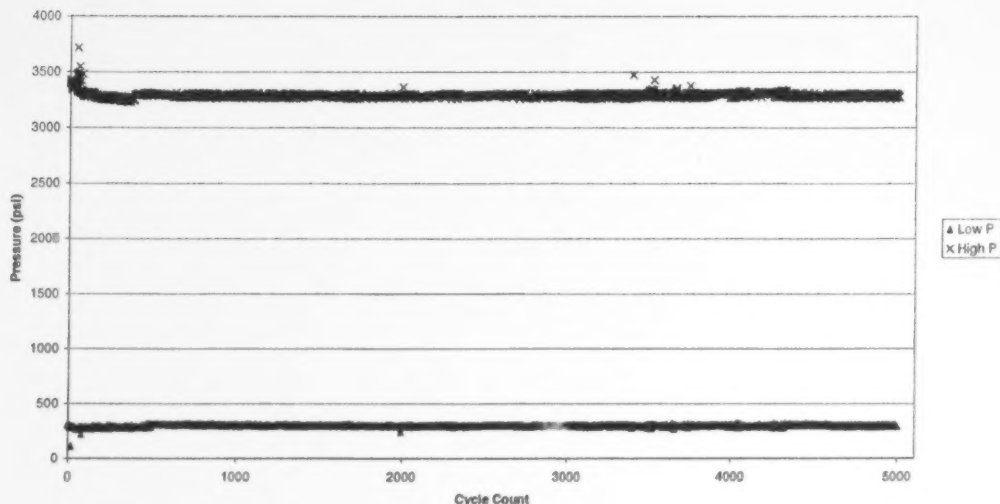


Figure 9: Dynetek H3217, Plot of High and Low pressure values for 5,000 cycles at above 60°C

DYN-H3217 Environmental Cycling
5,000 cycles (Hot) Temperature Plot

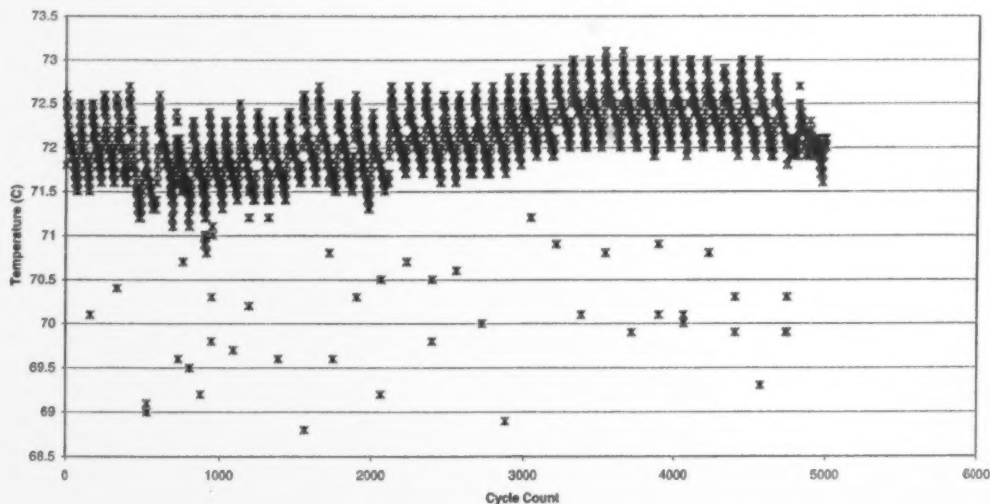


Figure 10: Dynetek H3217, Plot of temperature values for 5,000 cycles at above 60°C

TEST REPORT

CSA B339-96 (9.13.3) CYCLING TESTS

DYN-H3217 Environmental Cycling
5,000 cycles (Cold) High/Low Pressure Plot

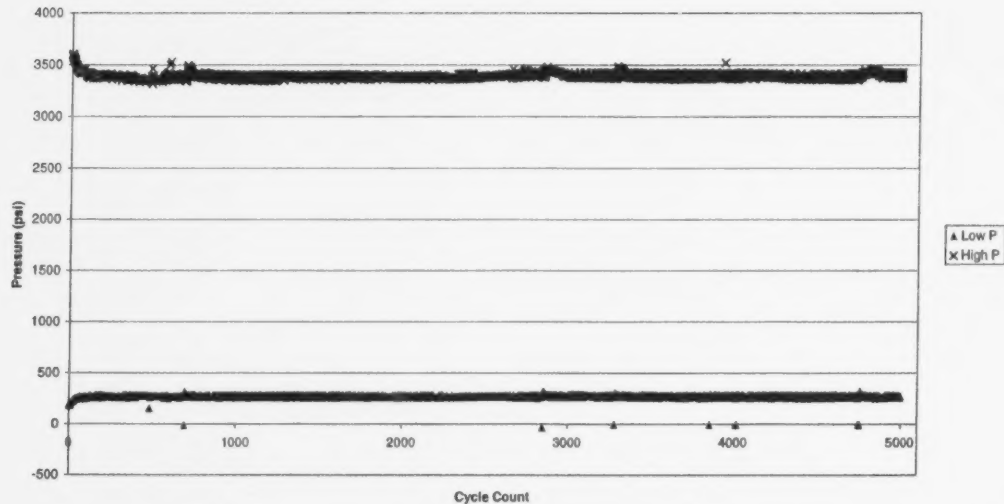


Figure 11: Dynetek H3217, Plot of High and Low pressure values for 5,000 cycles at below -50°C

DYN-H3217 Environmental Cycling
5,000 cycles (Cold) Temperature Plot

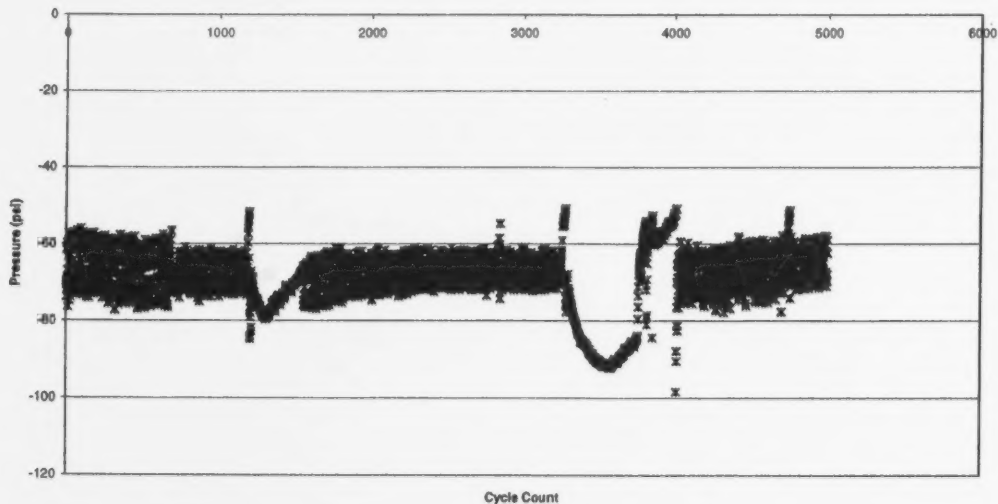


Figure 12: Dynetek H3217, Plot of temperature values for 5,000 cycles at below -50°C

CSA B339-96 (9.13.3) CYCLING TESTS

DYN-H3217 Environmental Cycle
30 cycles (Ambient) Pressure Plot

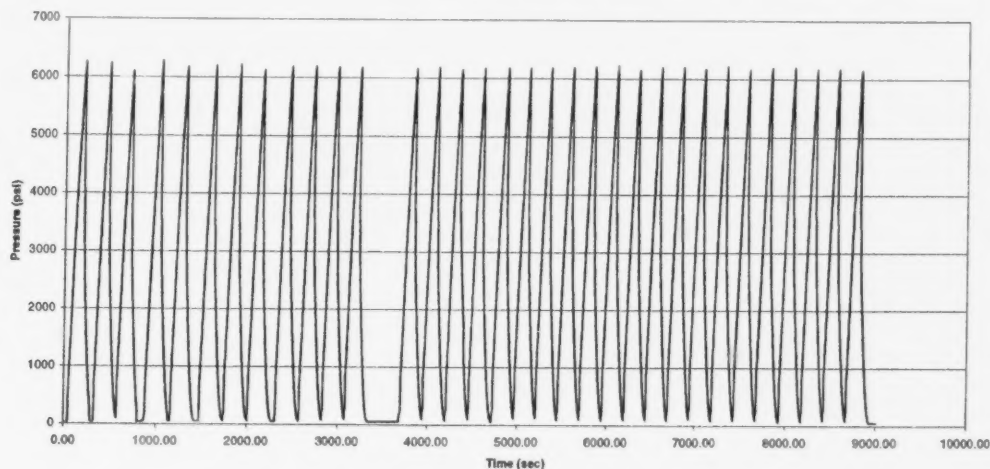


Figure 13: Dynetek H3217, Plot of pressure values for 30 cycles at ambient temperature

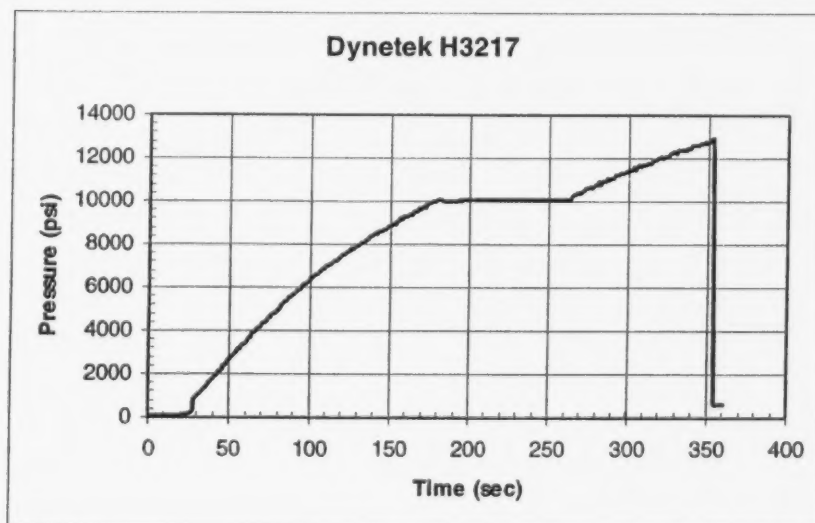


Figure 14: Dynetek H3217, Plot of burst pressure

TEST REPORT

CSA B339-96 (9.13.3) CYCLING TESTS



Figure 15: Dynetek H3217, Cylinder after rupture

Cylinder H3212

The cylinder showed no signs of visually observable damage, distortion, or leakage after completion of pressure cycling.

The cylinder leaked at a recorded pressure of 754.3 bar (10,940 psi).

TEST REPORT

CSA B339-96 (9.13.3) CYCLING TESTS

DYN-H3212 Environmental Cycling
5,000 cycles (Hot) High/Low Pressure Plot

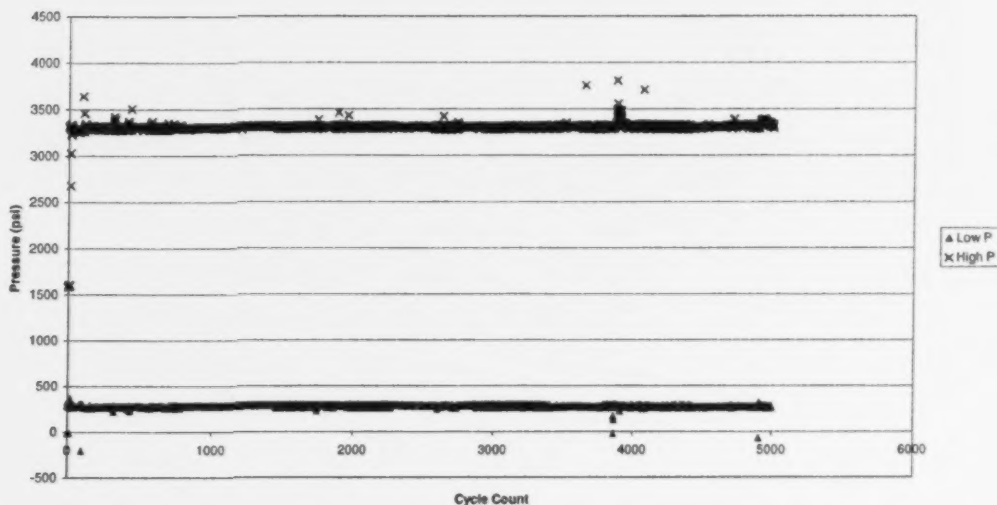


Figure 16: Dynetek H3212, Plot of High and Low pressure values for 5,000 cycles at above 60°C

DYN-H3212 Environmental Cycling
5,000 cycles (Hot) Temperature Plot

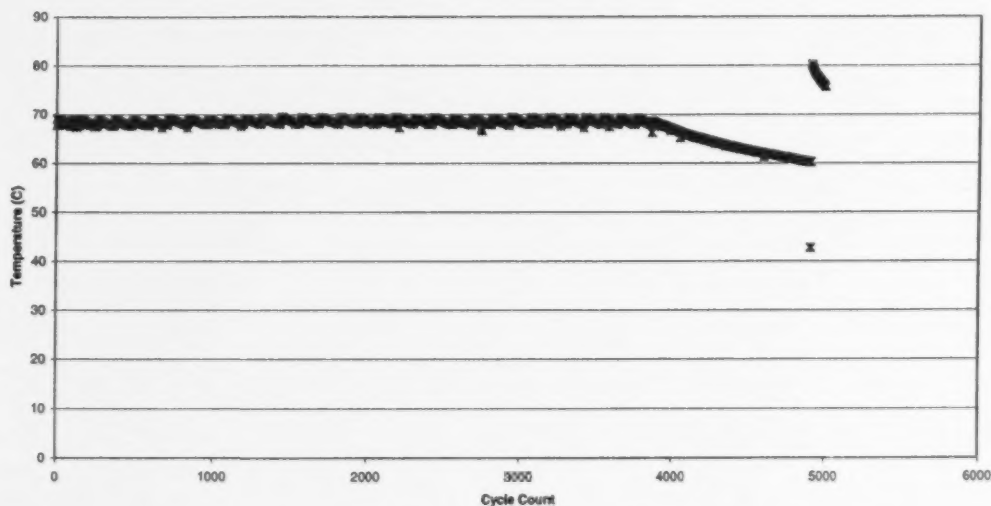


Figure 17: Dynetek H3212, Plot of temperature values for 5,000 cycles at above 60°C

TEST REPORT

CSA B339-96 (9.13.3) CYCLING TESTS

DYN-H3212 Environmental Cycling
5,000 cycles (Cold) High/Low Pressure Plot

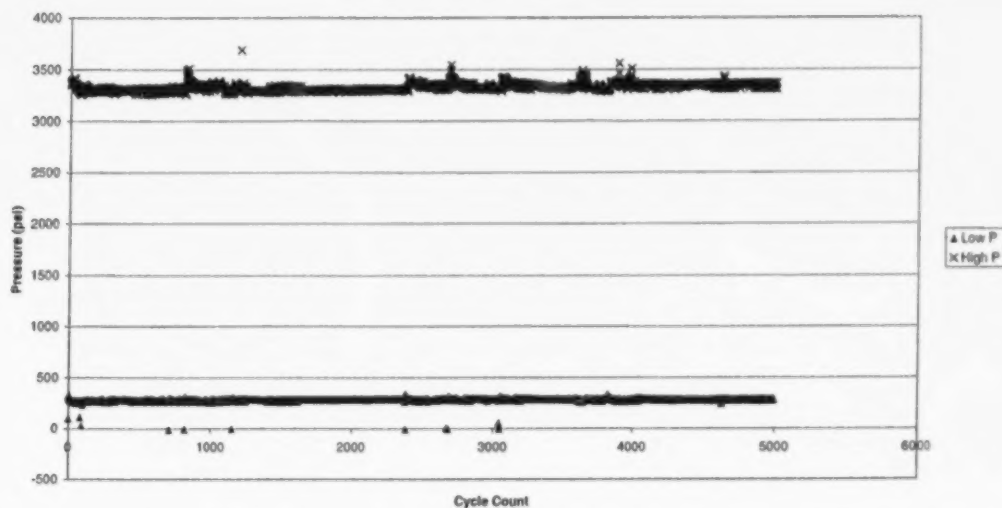


Figure 18: Dynetek H3212, Plot of High and Low pressure values for 5,000 cycles at below -50°C

DYN-H3212 Environmental Cycling
5,000 cycles (Cold) Temperature Plot

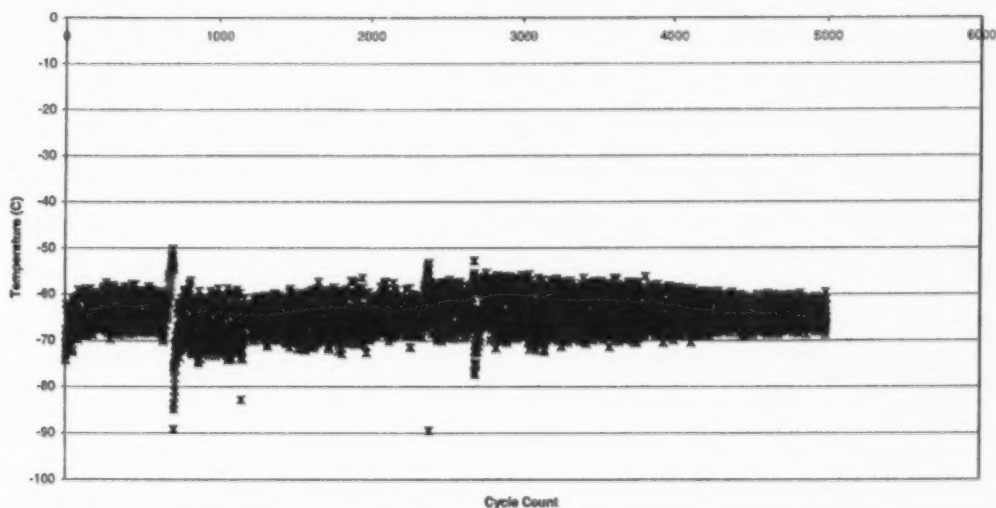


Figure 19: Dynetek H3212, Plot of temperature values for 5,000 cycles at below -50°C

CSA B339-96 (9.13.3) CYCLING TESTS

DYN-H3212 Environmental Cycle
30 cycles (Ambient) Pressure Plot

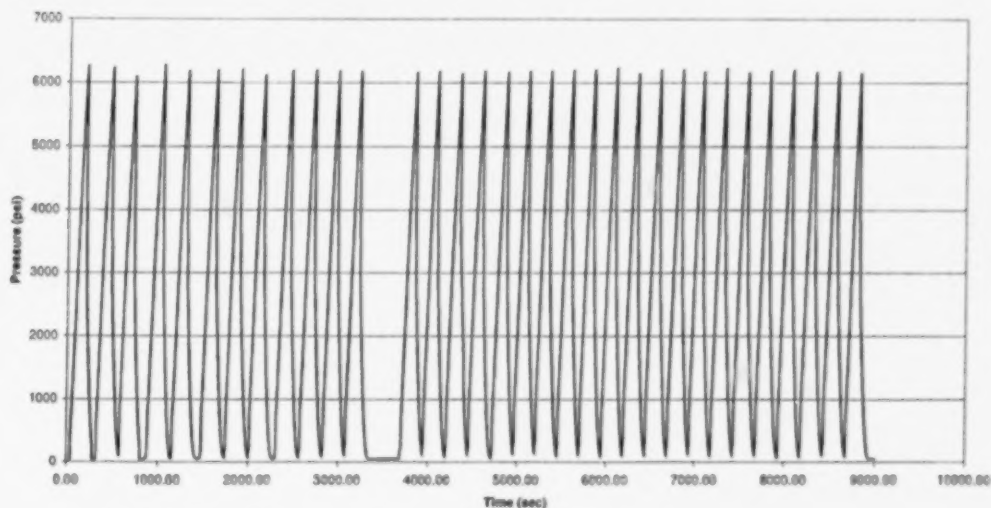


Figure 20: Dynetek H3212, Plot of pressure values for 30 cycles at ambient temperature

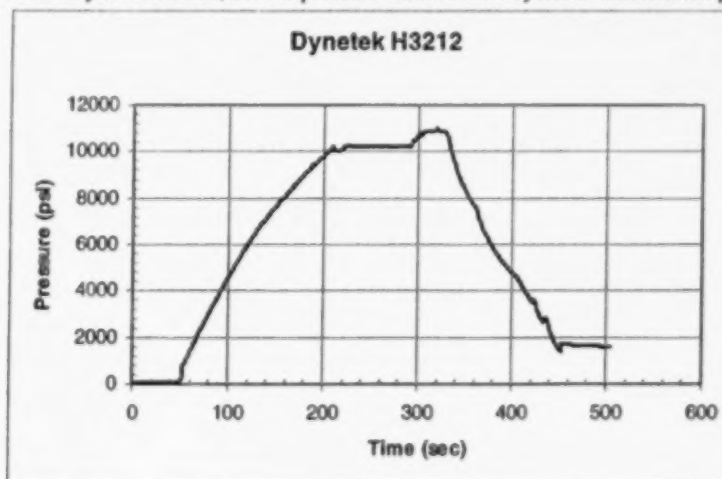


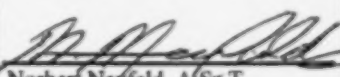
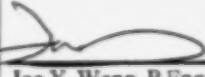
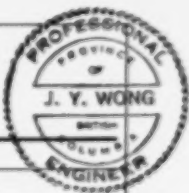
Figure 21: Dynetek H3212, Plot of burst pressure

TEST REPORT

CSA B339-96 (9.13.3) CYCLING TESTS



Figure 22: Dynetek H3212, Cylinder after leak

Tested By:  Norbert Nedfeld, A.Sc.T. Date: August 14, 2002	Approved By:  Joe Y. Wong, P.Eng	
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TEST REPORT

CSA B339-01 (9.13.3) CYCLING TESTS

Prepared for: Dynetek Industries Ltd.

Project Number: 12670-36

Manufacturer: Dynetek Industries Ltd.
Part Type: W150TDG223G5N
Serial Number: H3168, H3163, H3157
Part Data: Type-3 Cylinder, 223 bar (3240 psi) Service Pressure

TEST CONDUCTED:

The following test was conducted in accordance with:

- CSA B339-01, Clause 9.13.3 (a): Ambient Temperature Cycling Test
- CSA B339-01, Clause 9.13.3 (b): Environmental Cycling Test

TEST PROCEDURE:

Cycling tests shall be performed hydrostatically at a rate not exceeding 4 cycles /min from approximately 0 kPa to the specified pressure. Testing shall be as follows:

- Ambient temperature cycling test. One cylinder shall be cycling tested at ambient temperature with out failure
 - to service pressure to 10 000 cycles (Figures 1, 5), and
 - to 1.11 times test pressure for 30 cycles (Figures 2, 6)
- Environmental cycling test. One cylinder free of any protective coating, shall be tested in accordance with the following sequence without distortion, deterioration, or failure:
 - conditioning for 48 h, without pressure, at 60° C or higher at 95% or greater relative humidity;
 - cycling testing to service pressure for 5 000 cycles under the same condition (Figures 9, 10);
 - stabilization without pressure at ambient conditions;
 - cycling testing to service pressure for 5 000 cycles at -50° C or lower (Figures 11, 12);
 - stabilization without pressure at ambient conditions;
 - cycle testing to 1.11 times test pressure for 30 cycles at ambient temperature (Figure 13).
- The cylinder shall then be tested hydrostatically to destruction and the burst pressure recorded (Figure 14).

TEST RESULTS:

Cylinder H3168

The cylinder showed no signs of visually observable damage, distortion, or leakage after completion of pressure cycling.

The cylinder leaked at a recorded pressure of 852.9 bar (12,370 psi).

CSA B339-01 (9.13.3) CYCLING TESTS

**DYN-H3168 Ambient Cycle
10,000 cycles High/Low Pressure Plot**

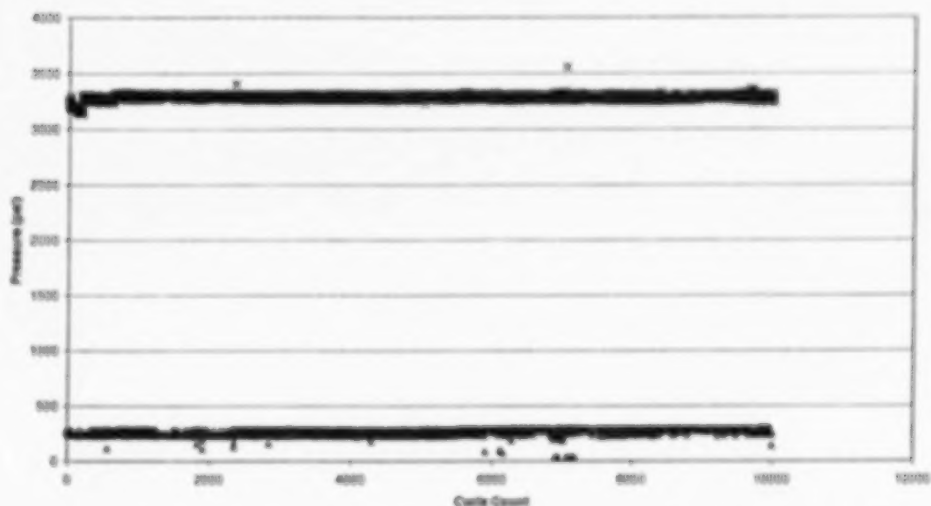


Figure 1: Dynetek H3168, Plot of High and Low pressure values for 10,000 cycles

**DYN-H3168 Ambient Cycle
30 cycles High/Low Pressure Plot**

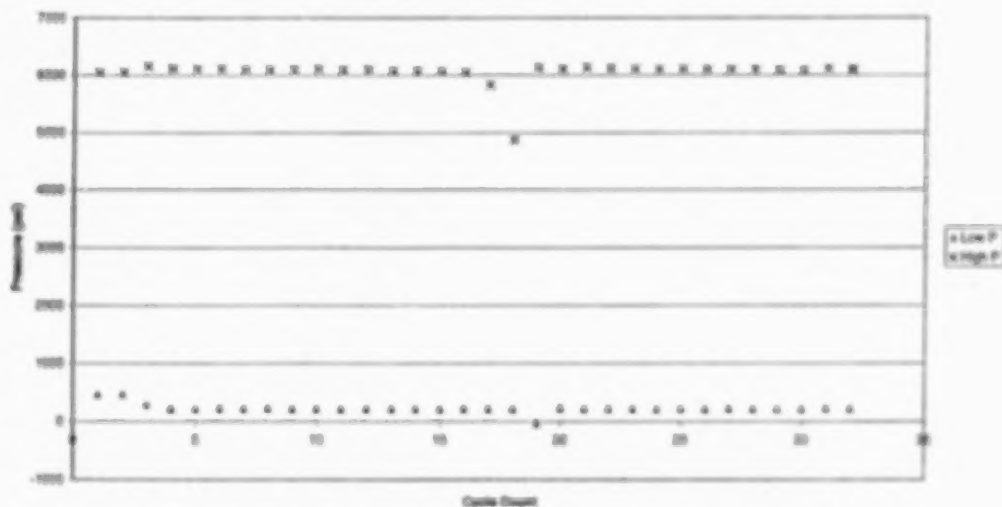


Figure 2: Dynetek H3168, Plot of High and Low pressure values for 30 cycles

TEST REPORT

CSA B339-01 (S.13.3) CYCLING TESTS

DYN-H3168 Ambient Cycle Burst

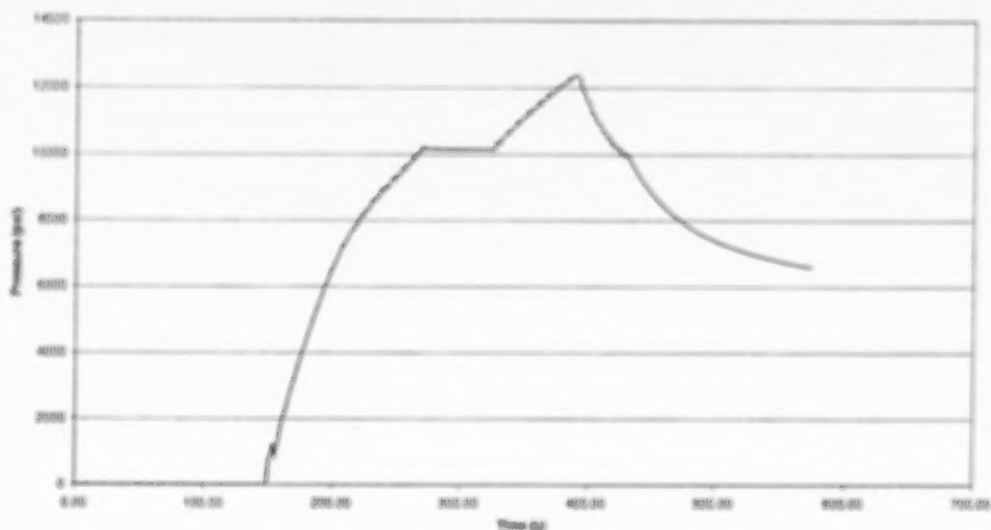


Figure 3: Dynetek H3168, Plot of burst pressure

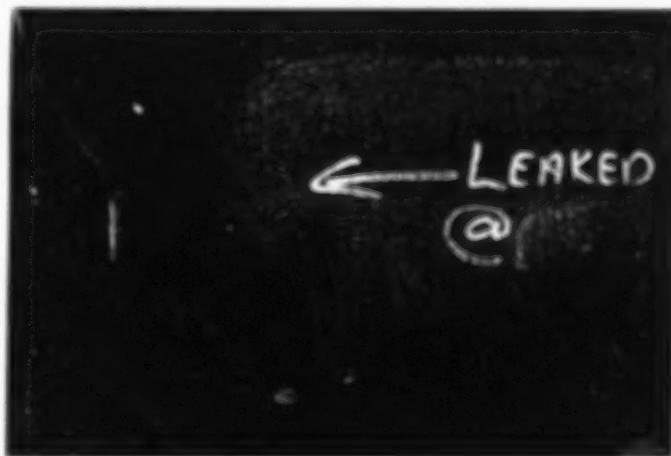


Figure 4: Dynetek H3168, Cylinder after leaking

Cylinder H3168

The cylinder showed no signs of visually observable damage, distortion, or leakage after completion of pressure cycling.

The cylinder leaked at a recorded pressure of 904.66 bar (13,121 psi).

TEST REPORT

CSA B339-01 (9.13.3) CYCLING TESTS

DYN-H3163 Ambient Cycle
10,000 cycles High/Low Pressure Plot

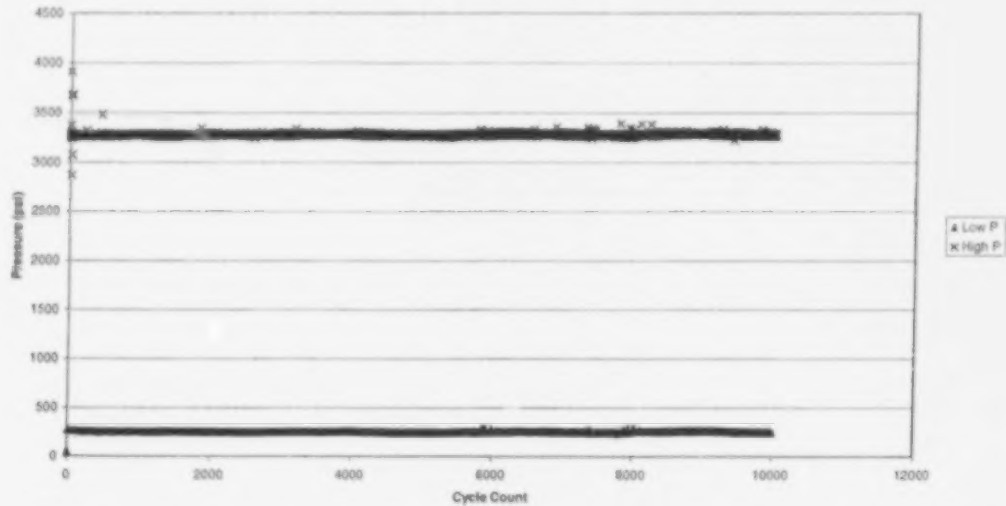


Figure 5: Dynetek H3163, Plot of High and Low pressure values for 10,000 cycles

DYN-H3163 Ambient Cycle
30 cycles High/Low Pressure Plot

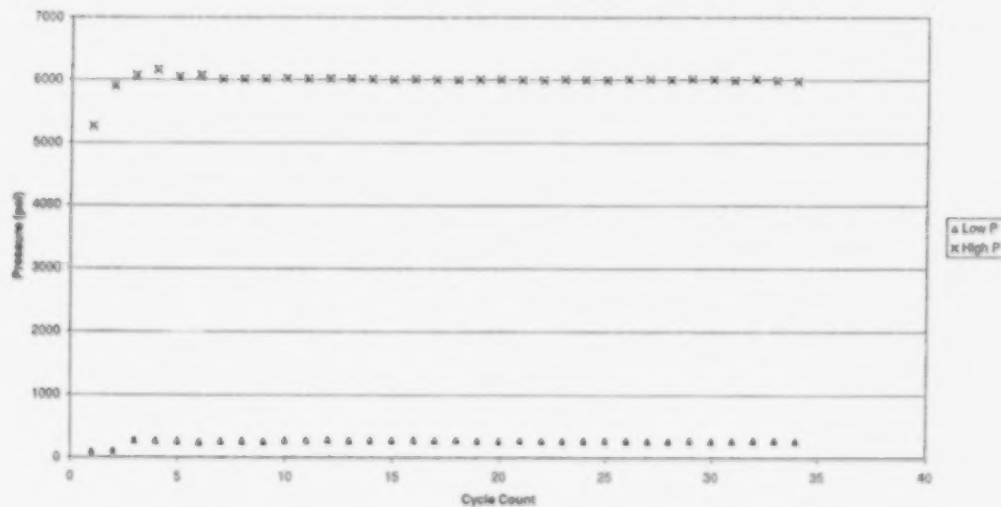


Figure 6: Dynetek H3163, Plot of High and Low pressure values for 30 cycles

TEST REPORT

CSA B339-01 (9.13.3) CYCLING TESTS

DYN-H3163 Ambient Burst

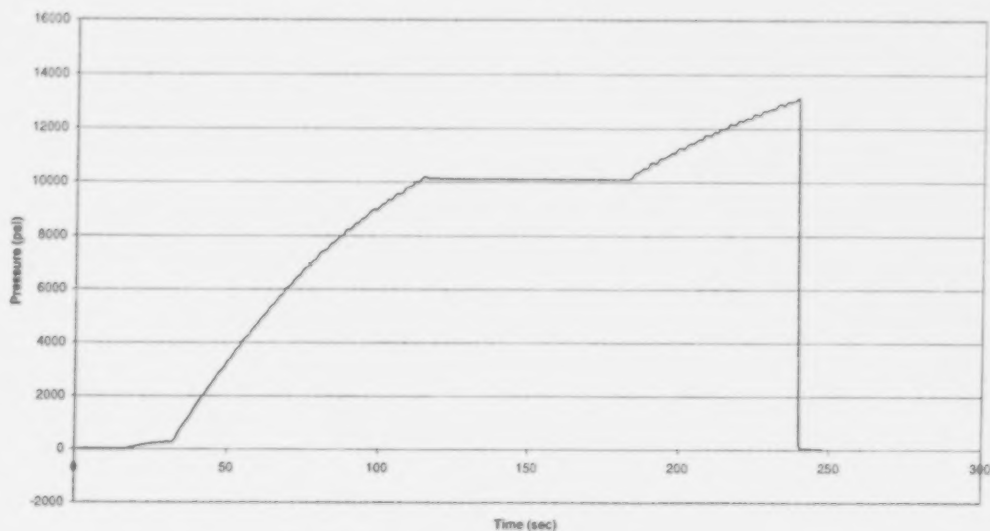


Figure 7: Dynetek H3163, Plot of burst pressure

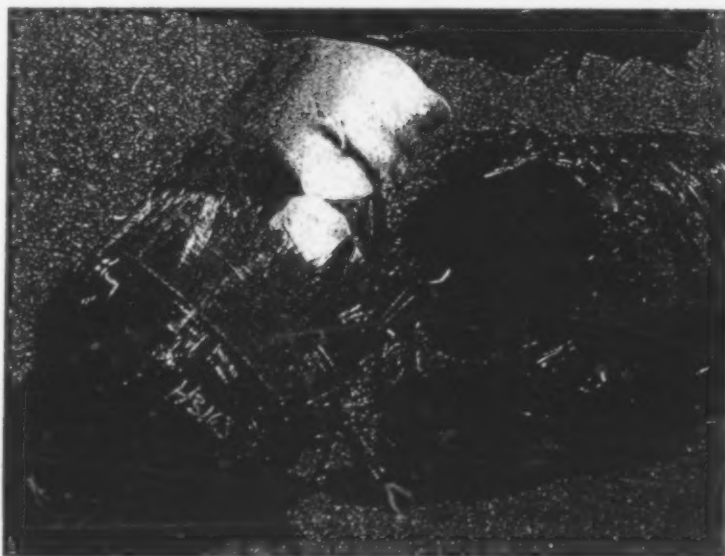


Figure 8: Dynetek H3163, Cylinder after rupture

Cylinder H3157

The cylinder showed no signs of visually observable damage, distortion, or leakage after completion of pressure cycling.

TEST REPORT

CSA B339-01 (9.13.3) CYCLING TESTS

The cylinder leaked at a recorded pressure of 902.52 bar (13,090 psi).

DYN-H3157 Environmental Cycle
5,000 (Hot) High/Low Pressure Plot

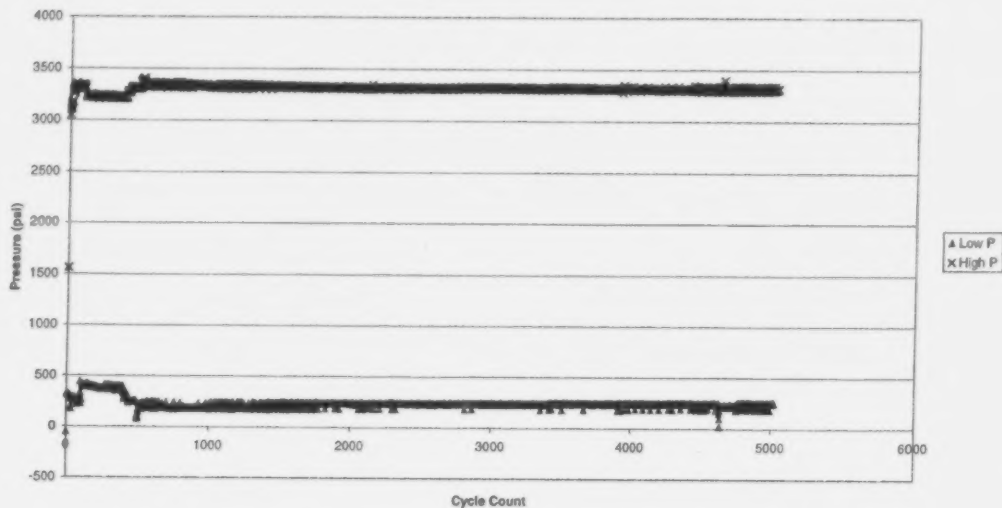


Figure 9: Dynetek H3157, Plot of High and Low pressure values for 5,000 cycles at above 60°C

DYN-H3157 Environmental Cycle
5,000 cycles (Hot) Temperature Plot

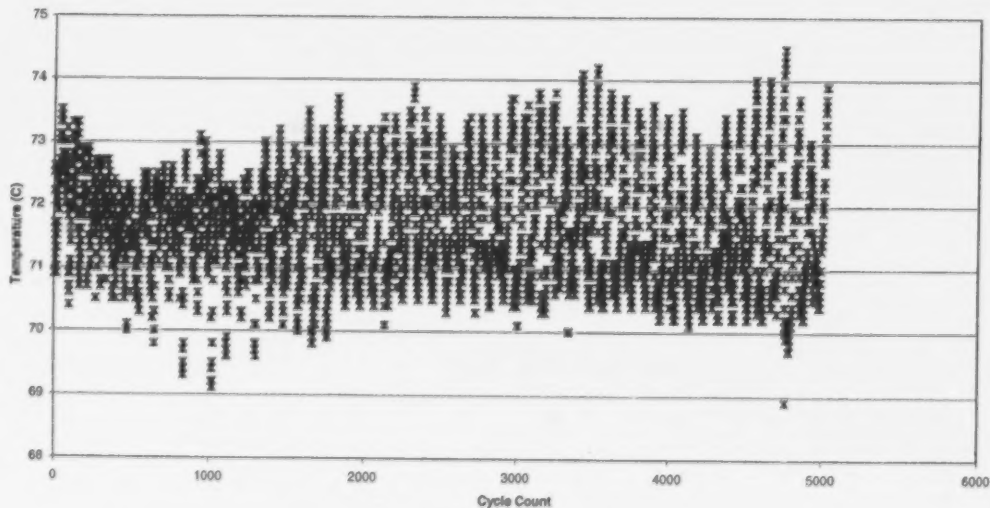


Figure 10: Dynetek H3157, Plot of temperature values for 5,000 cycles at above 60°C

TEST REPORT

CSA B339-01 (9.13.3) CYCLING TESTS

DYN-H3157 Environmental Cycle
5,000 cycles (Cold) High/Low Pressure Plot

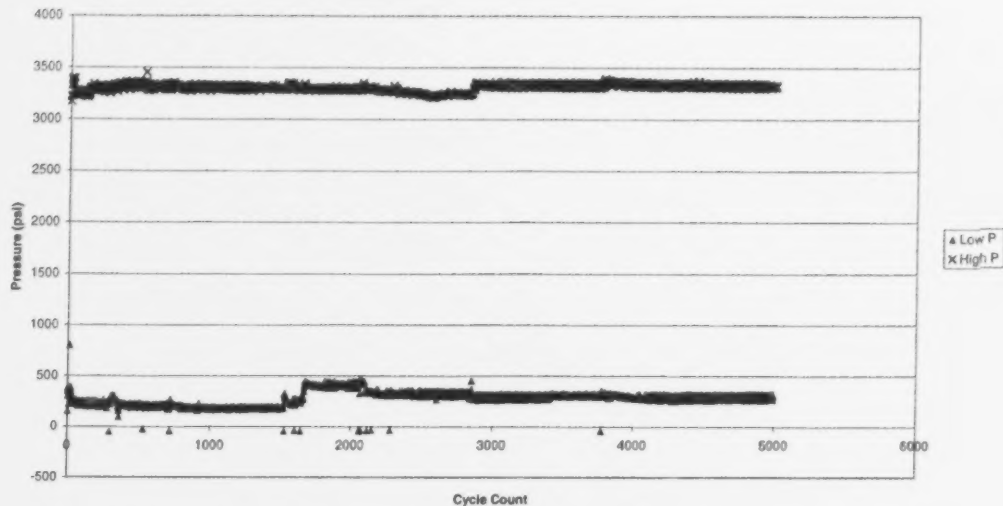


Figure 11: Dynetek H3157, Plot of High and Low pressure values for 5,000 cycles at below -50°C

DYN-H3157 Environmental Cycle
5,000 cycles (Cold) Temperature Plot

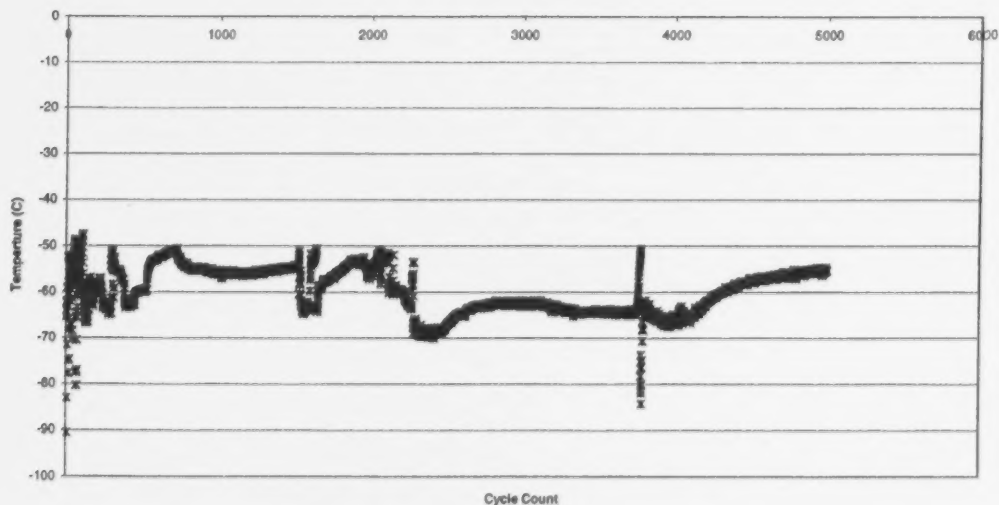


Figure 12: Dynetek H3157, Plot of temperature values for 5,000 cycles at below -50°C

TEST REPORT

CSA B339-01 (9.13.3) CYCLING TESTS

DYN-H3157 Environmental Cycle
30 cycles (Ambient) Pressure Plot

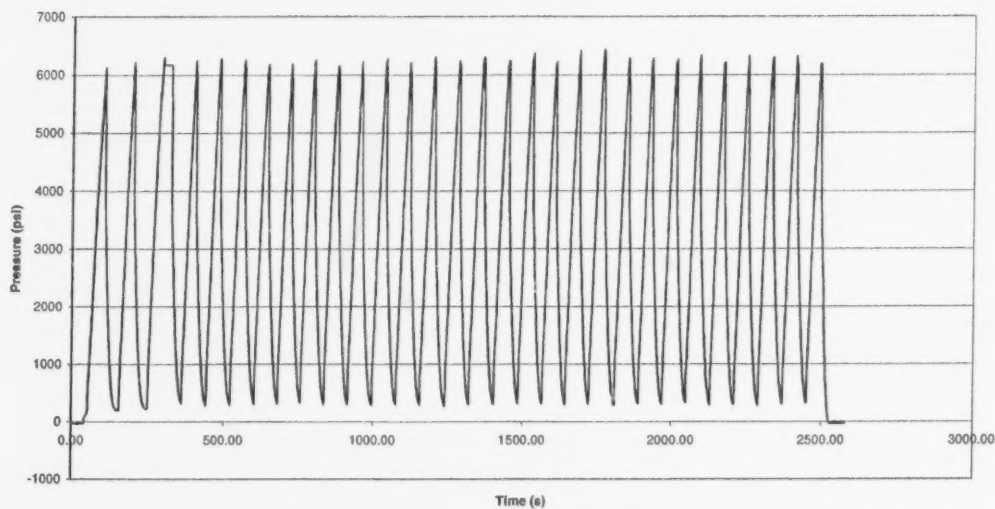


Figure 13: Dynetek H3157, Plot of pressure values for 30 cycles at ambient

DYN-H3157 Environmental Burst Plot

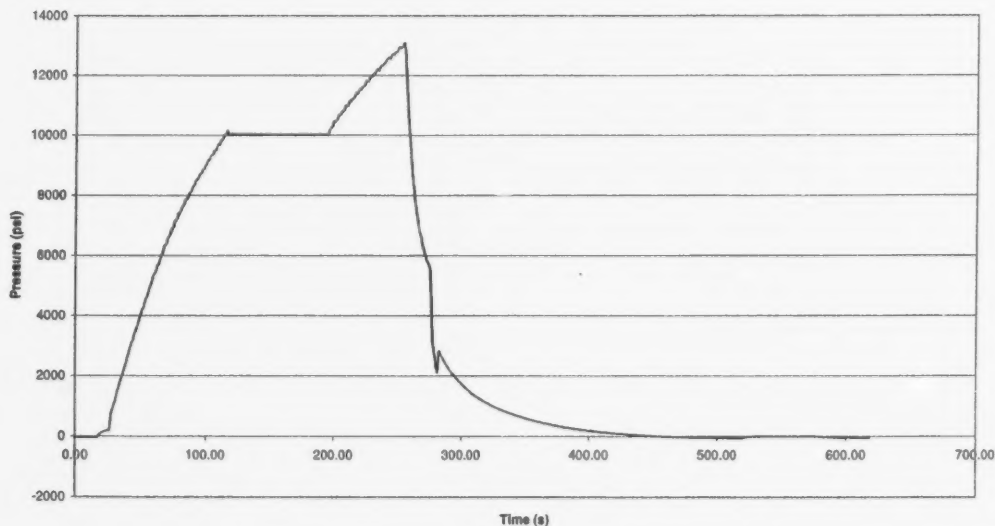


Figure 14: Dynetek H3157, Plot of burst pressure

TEST REPORT

CSA B339-01 (9.13.3) CYCLING TESTS

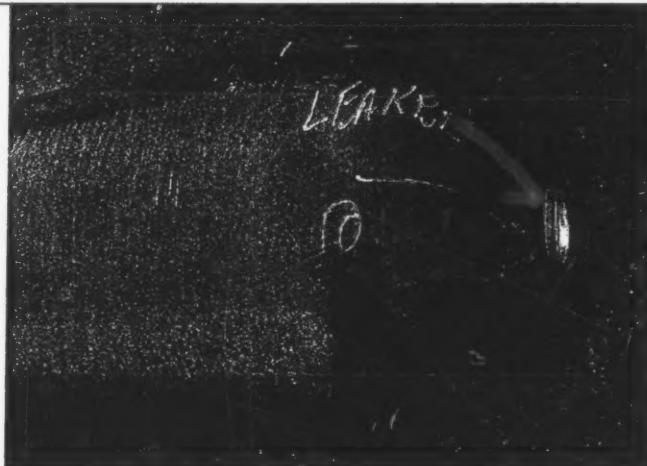


Figure 15: Dynetek H3157, Cylinder after leaking

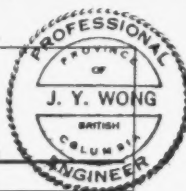
Tested By:

Norbert Neufeld, A.Sc.T.

Date: August 12, 2002

Approved By:

Joe Y. Wong, P.Eng



CSA B339-01 (9.13.6) BONFIRE TESTS

Prepared for: Dynetek Industries Ltd.

Project Number: 12670-36

Manufacturer: Dynetek Industries Ltd.
Part Type: W150TDG223G5N
Serial Number: H3164, H3165
Part Data: Type-3 Cylinder, 223 bar (3240 psi) Service Pressure
VTI Valve and PRD

TEST CONDUCTED:

The following test was conducted in accordance with:

- CSA B339-01, Clause 9.13.6: Bonfire Test

TEST PROCEDURE:

The test was performed in general accordance with Clause 9.13.6 (Bonfire Tests) of the CAN/CSA-B339-01 standard. One finished cylinder was provided for the bonfire test. The cylinder was charged to 223 bar (70°F) with Compressed Natural Gas. The cylinder was placed above a burner apparatus capable of enveloping the cylinder system in an environment having a temperature of approximately 648°C in 5 minutes. Four thermocouples were positioned on the cylinder: one on the PRD, a second midway along the cylinder, a third midway along the cylinder, and a final fourth thermocouple on the tail end of the cylinder. A schematic of the test setup is shown in Figure 1. The thermocouple temperatures (Figures 3, 8) and container pressure (Figures 2, 7) were recorded during the test.

The cylinder was then burst hydrostatically (Figures 4, 9).

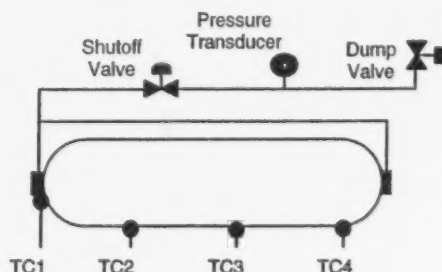


Figure 1: Bonfire Schematic

TEST RESULTS:

Cylinder H3164

The pressure relief device activated after 58 seconds without cylinder failure. The bonfire test pressure and temperature data is appended. The cylinder ruptured at a pressure recorded to be 836.3 bar (12,129 psi).

TEST REPORT

CSA B339-01 (9.13.6) BONFIRE TESTS

Bonfire Pressure Data
Dynetek Cylinder#: H3164

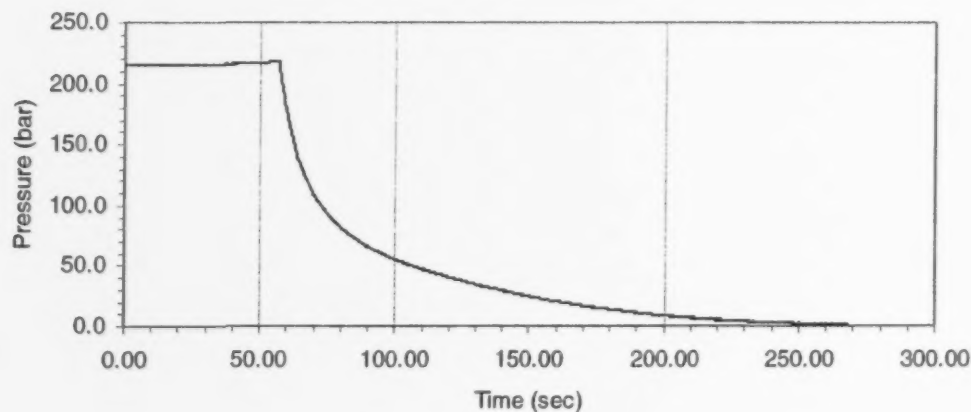


Figure 2: Dynetek H3164, Bonfire pressure plot

Bonfire Temperature Data
Dynetek Cylinder#: H3164

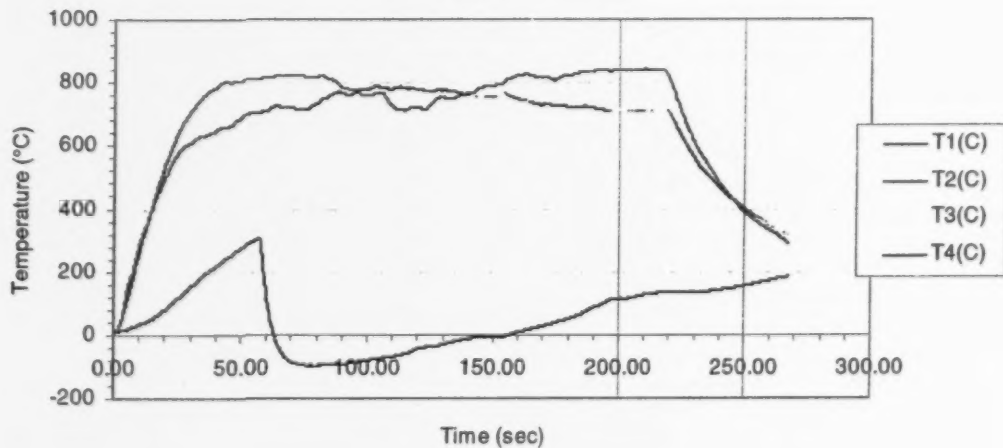


Figure 3: Dynetek H3164, Bonfire temperature plot

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CSA B339-01 (9.13.6) BONFIRE TESTS

DYN-H3164 Bonfire Burst

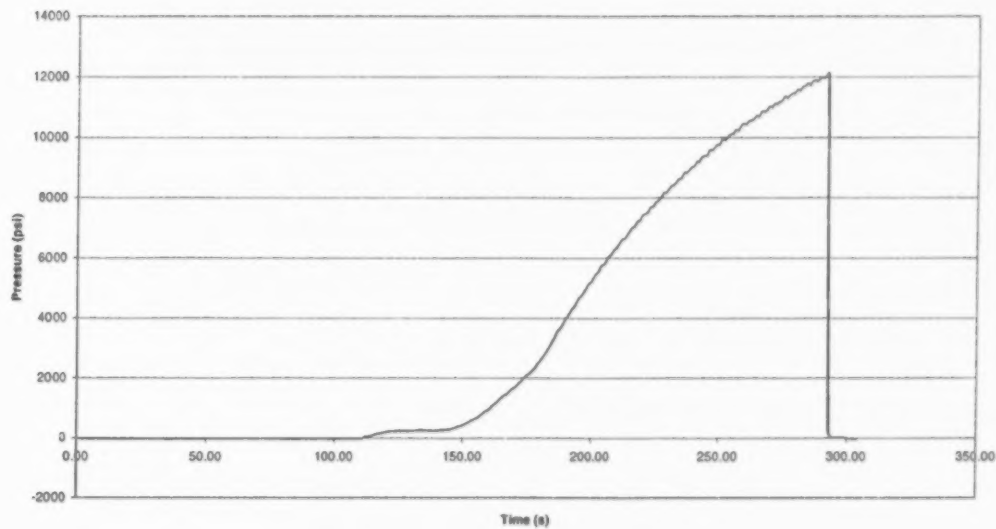


Figure 4: Dynetek H3164, Hydrostatic burst pressure plot

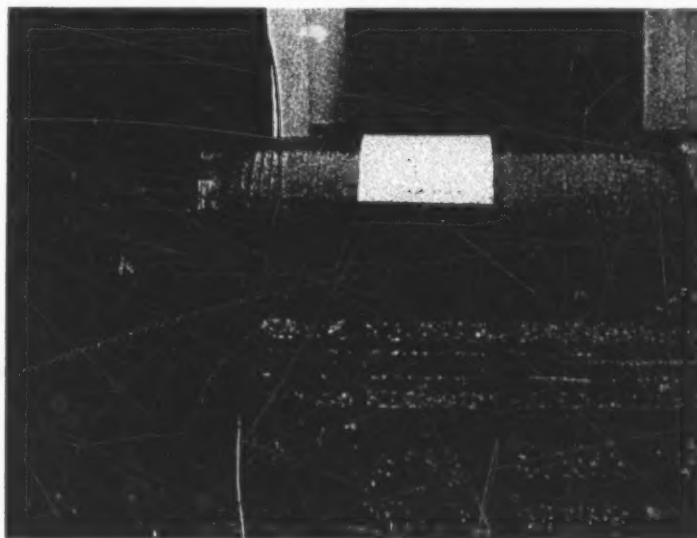


Figure 5: Dynetek H3164, Image of cylinder bonfire apparatus

TEST REPORT

CSA B339-01 (9.13.6) BONFIRE TESTS



Figure 6: Dynetek H3164, Image of cylinder after burst

Cylinder H3165

The pressure relief device activated after 98 seconds without cylinder failure. The bonfire test pressure and temperature data is appended. The cylinder ruptured at a pressure recorded to be 841.0 bar (12,197 psi).

Bonfire Pressure Data Dynetek Cylinder#: H3165

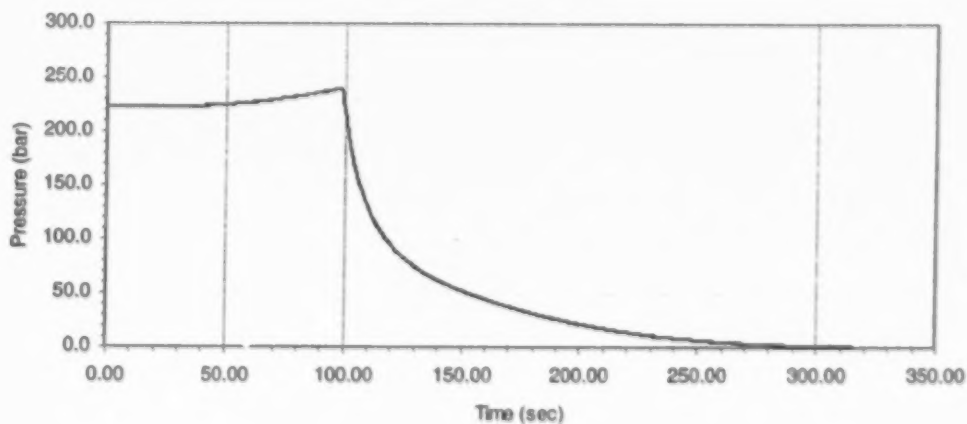


Figure 7: Dynetek H3165, Bonfire pressure plot

CSA B339-01 (9.13.6) BONFIRE TESTS

**Bonfire Temperature Data
Dynetek Cylinder#: H3165**

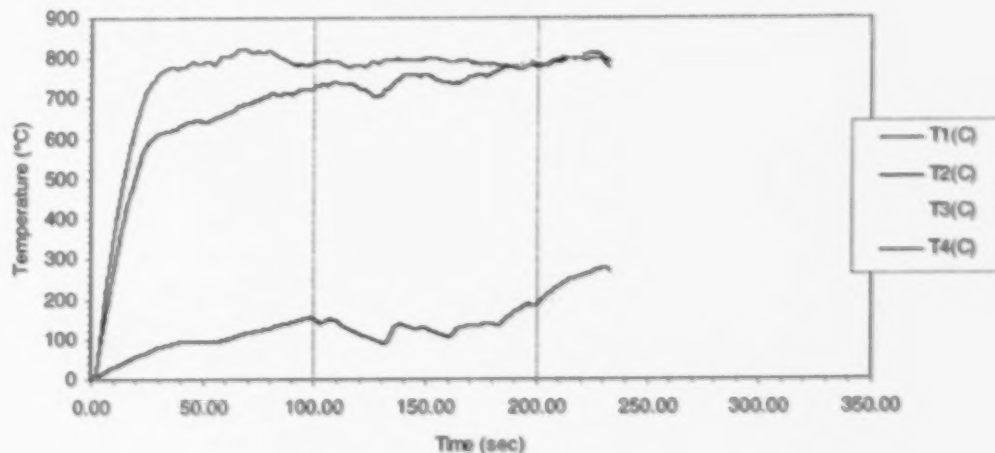


Figure 8: Dynetek H3165, Bonfire temperature plot

DYN-H3165 Bonfire Burst

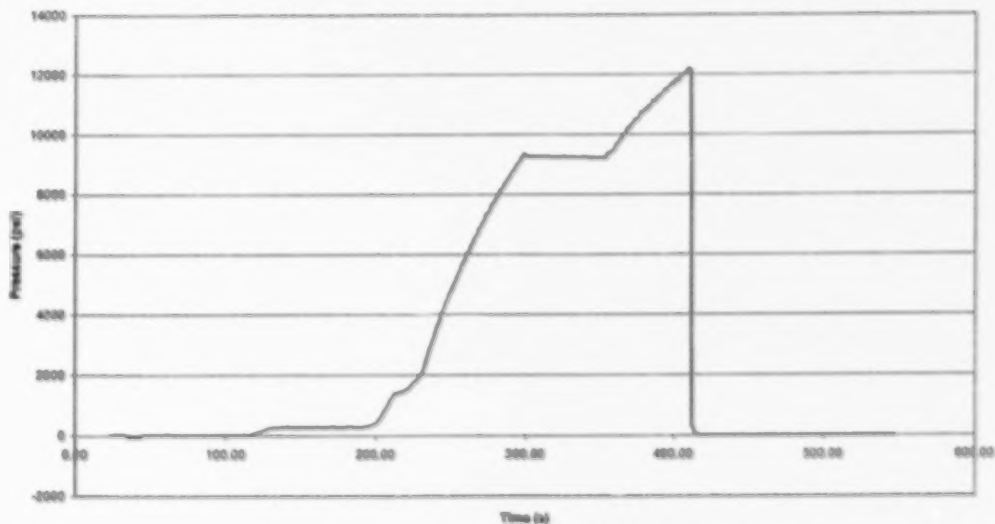


Figure 9: Dynetek H3165, Hydrostatic burst pressure plot

TEST REPORT

CSA B339-01 (9.13.6) BONFIRE TESTS

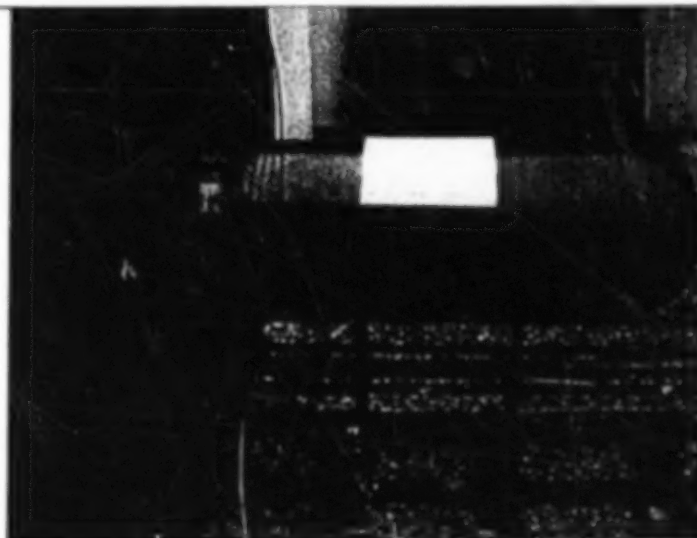
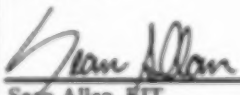
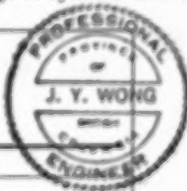


Figure 10: Dynetek H3165, Image of cylinder bonfire apparatus



Figure 11: Dynetek H3165, Image of cylinder after burst

Tested By:  Sean Allan, EIT Date: August 12, 2002	Approved By:  Joe Y. Wong, P.Eng 
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TEST REPORT

CSA B339-01 (9.13.4) BURST TEST

Prepared for: Dynetek Industries Ltd.

Project Number: 12670-36

Manufacturer: Dynetek Industries Ltd.
Part Type: W150TDG223G5N
Serial Number: H3169
Part Data: Type-3 Cylinder, 223 bar (3240 psi) Service Pressure

TEST CONDUCTED:

The following test was conducted in accordance with:

- CSA B339-01, Clause 9.13.4: Burst Test

TEST PROCEDURE:

A complete cylinder shall be tested hydrostatically to destruction by pressurizing at a uniform rate up to the failure pressure (Figure 1). Burst pressure shall be at least 3.4 times the service pressure. Failure shall initiate in the cylinder sidewall.

TEST RESULTS:

The cylinder ruptured at 921.14 bar (13,360 psi).

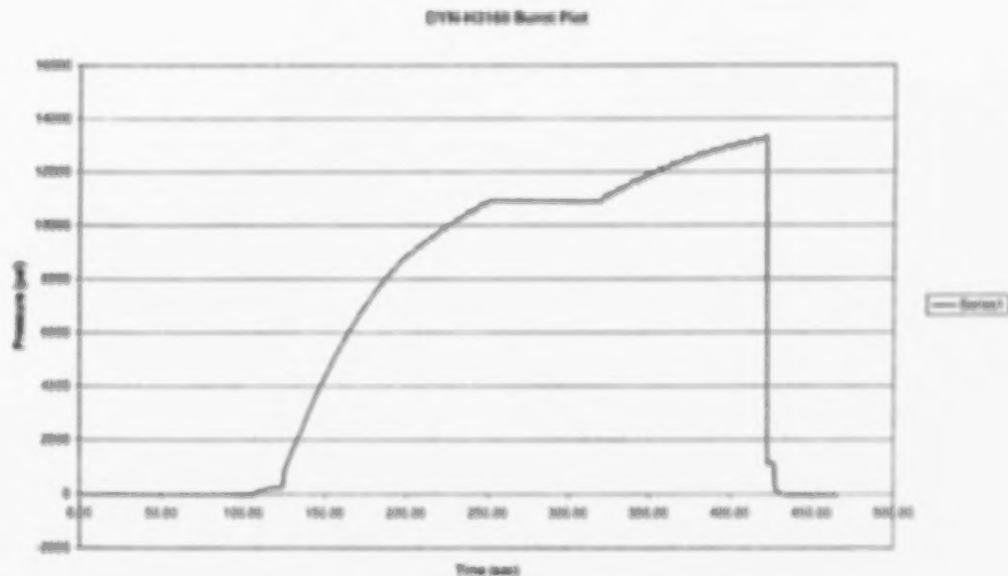


Figure 1: Cylinder H3169, Burst pressure plot

CSA B339-01 (9.13.4) BURST TEST



Figure 2: Cylinder H3169, image after rupture

Tested By:

Approved By:

Norbert Newfield, A.Sc.T.

Joe Y. Wong, P.Eng.

Date: August 12, 2000





TEST REPORT

DOT-CFFC-10 (c) DROP TEST

Prepared for: Dynetek Industries Ltd.

Project Number: 12670-36

Manufacturer: Dynetek Industries Ltd.
Part Type: W150TDG223G8
Serial Number: H3156
Part Data: Type-3 Cylinder, 223 bar (3240 psi) Service Pressure

TEST CONDUCTED:

The following test was conducted in accordance with:

- DOT-CFFC 10(c): Drop Test

TEST PROCEDURE:

The representative empty cylinder complete with valve shall be dropped from a height of 3 meters onto a concrete surface in three configurations:

- 1) The cylinder shall be dropped vertically onto its end.
- 2) The cylinder shall be dropped horizontally onto its sidewall.
- 3) The cylinder shall be dropped horizontally onto a 3.8 x 0.48 cm piece of angle iron with the included angle in the downward position. The cylinder shall land at right angles to and on the heel edge of the angle iron, impacting approximately in the center of the sidewall.

The cylinder is then subject to a minimum of 1,000 cycles, pressurized between 10% of service pressure and service pressure at a rate not exceeding 10 cycles per minute (Figure 1). The minimum dwell time at the 90-100% range of each cycle was not less than 1.2 seconds.

The cylinder was then burst hydrostatically in accordance with DOT-CFFC-10(b)(i) (Figure 2).

TEST RESULTS:

The cylinder showed no signs of visually observable damage, distortion, or leakage after completion of pressure cycling.

The cylinder ruptured at a recorded pressure of 750.84 bar (10,890 psi).

TEST REPORT

DOT-CFFC-10 (c) DROP TEST

DYN-H3156 Drop Test
1,000 pressure cycles

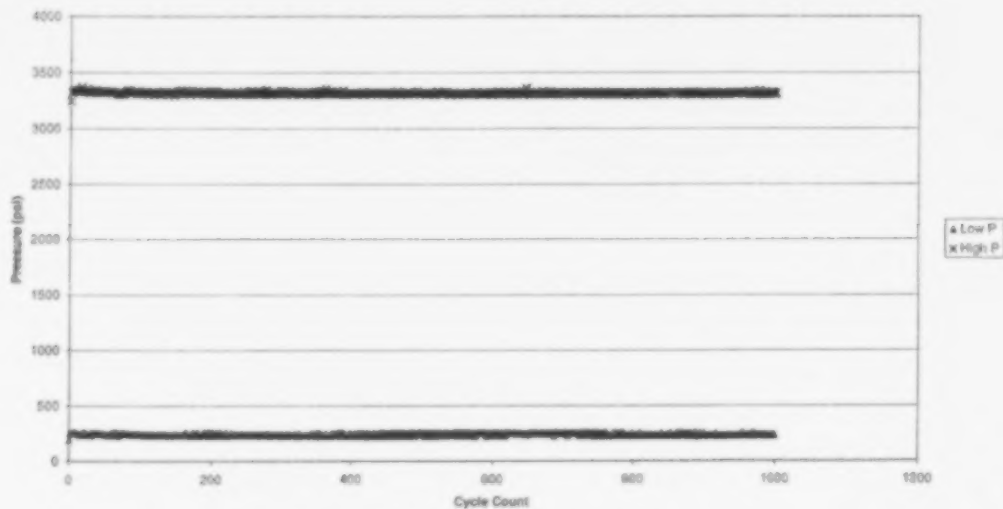


Figure 1: Dynetek H3156, Plot of 1,000 pressure cycles

Dynetek H3156 Drop Burst

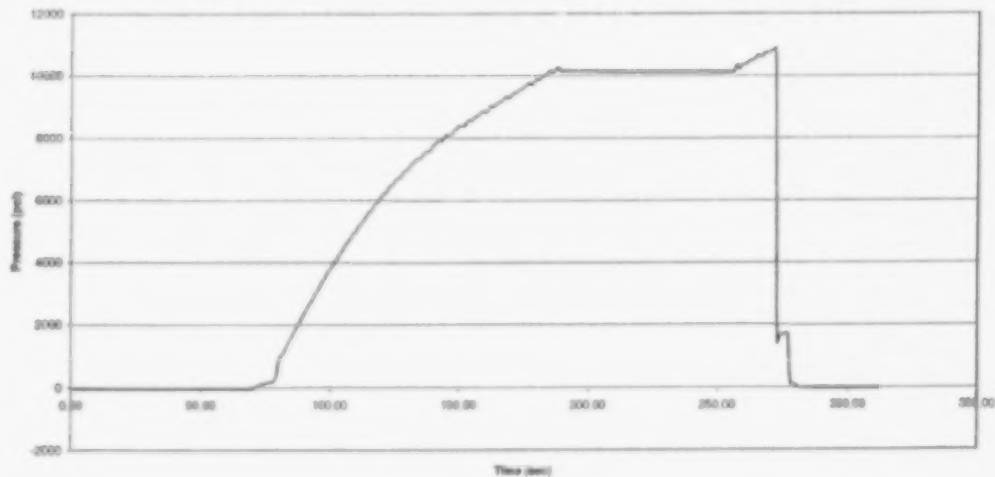


Figure 2: Dynetek H3156, Plot of burst pressure

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DOT-CFFC-10 (c) DROP TEST

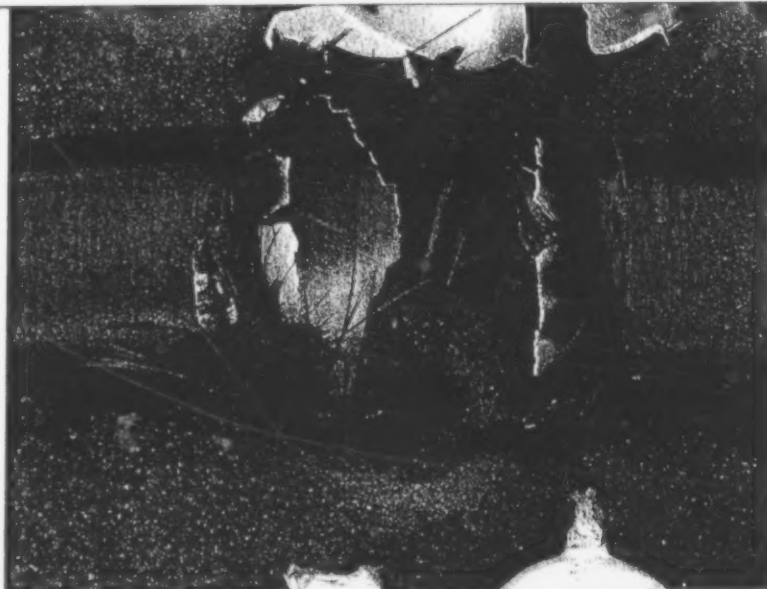
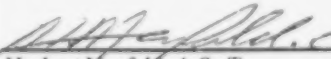
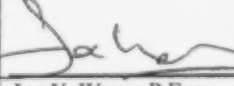
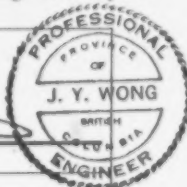


Figure 3: Dynetek H3156, Image after rupture

Tested By:	Approved By:
	
Norbert Neufeld, A.Sc.T.	Joe Y. Wong, P.Eng
Date: August 12, 2002	



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CSA B339-01 (9.13.5) GUNFIRE TEST

Prepared for: Dynetek Industries Ltd.

Project Number: 12670-36

Manufacturer: Dynetek Industries Ltd.
Part Type: W150TDG223G5N
Serial Number: H3167
Part Data: Type-3 Cylinder, 223 bar (3240 psi) Service Pressure

TEST CONDUCTED:

The following test was conducted in accordance with:

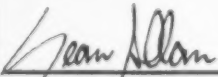
- CSA B339-01, Clause 9.13.5: Gunfire Test

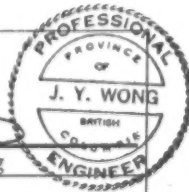
TEST PROCEDURE:

One representative cylinder, filled with air or nitrogen to service pressure, shall be impacted by a 7.5 mm calibre armour-piercing projectile having a velocity of approximately 850 m/s. The cylinder shall be so positioned that the projectile impact is in the cylinder sidewall wrapping at approximately a 45° angle and aimed to exit at the cylinder sidewall. The distance from the firing location to the test cylinder shall not exceed 45 m. The tested cylinder shall reveal no evidence of a fragmentation failure. The approximate size of entrance and exit openings shall be recorded.

TEST RESULTS:

One cylinder was tested according to the above criteria and exhibited no evidence of fragmentation failure.

Tested By:  Sean Allan/EIT Date: August 13, 2002	Approved By:  Joe Y. Wong, P.Eng
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TEST REPORT

DOT-CFFC-10 (c) DROP TEST

Prepared for: Dynetek Industries Ltd.

Project Number: 12670-36

Manufacturer: Dynetek Industries Ltd.
Part Type: V260TDG223G8
Serial Number: H3213
Part Data: Type-3 Cylinder, 223 bar (3240 psi) Service Pressure

TEST CONDUCTED:

The following test was conducted in accordance with:

- DOT-CFFC 10(c): Drop Test

TEST PROCEDURE:

The representative empty cylinder complete with valve shall be dropped from a height of 3 meters onto a concrete surface in three configurations:

- 1) The cylinder shall be dropped vertically onto its end.
- 2) The cylinder shall be dropped horizontally onto its sidewall.
- 3) The cylinder shall be dropped horizontally onto a 3.8 x 0.48 cm piece of angle iron with the included angle in the downward position. The cylinder shall land at right angles to and on the heel edge of the angle iron, impacting approximately in the center of the sidewall.

The cylinder is then subject to a minimum of 1,000 cycles, pressurized between 10% of service pressure and service pressure at a rate not exceeding 10 cycles per minute (Figure 1). The minimum dwell time at the 90-100% range of each cycle was not less than 1.2 seconds.

The cylinder was then burst hydrostatically in accordance with DOT-CFFC-10(b)(i) (Figure 2).

TEST RESULTS:

The cylinder showed no signs of visually observable damage, distortion, or leakage after completion of pressure cycling.

The cylinder ruptured at a recorded pressure of 552.9 bar (8,019 psi).

TEST REPORT

DOT-CFFC-10 (c) DROP TEST

DYN-H3213 Drop Test
1,000 pressure cycles

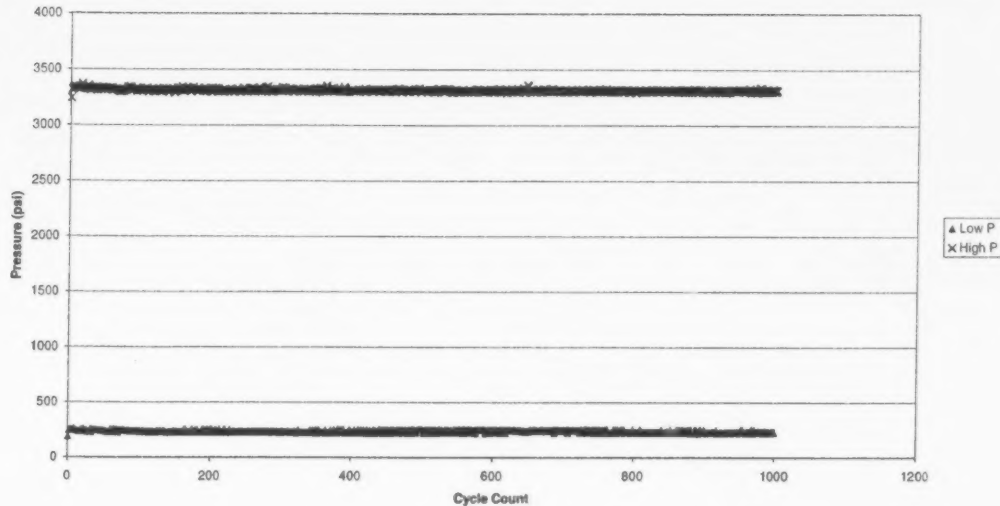


Figure 1: Dynetek H3213, Plot of 1,000 pressure cycles

DYN-H3213 Drop Burst

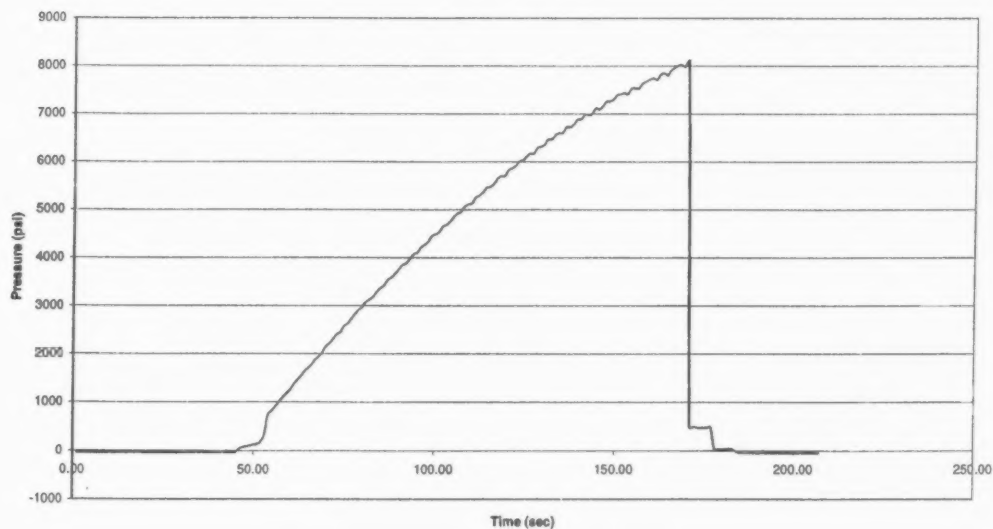


Figure 2: Dynetek H3213, Plot of burst pressure

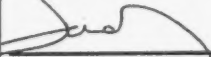
TEST REPORT

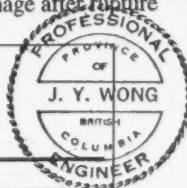
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DOT-CFFC-10 (c) DROP TEST



Figure 3: Dynetek H3213, Image after rupture

Tested By:	Approved By:
	
Norbert Neufeld, A.Sc.T.	Joe Y. Wong, P.Eng.
Date: August 12, 2002	



TEST REPORT

DOT-CFFC-10 (c) DROP TEST

Prepared for: Dynetek Industries Ltd.

Project Number: 12670-36

Manufacturer: Dynetek Industries Ltd.
Part Type: V260TDG223G8
Serial Number: H3220
Part Data: Type-3 Cylinder, 223 bar (3240 psi) Service Pressure

TEST CONDUCTED:

The following test was conducted in accordance with:

- DOT-CFFC 10(c): Drop Test

TEST PROCEDURE:

The representative empty cylinder complete with valve shall be dropped from a height of 3 meters onto a concrete surface in three configurations:

- 1) The cylinder shall be dropped vertically onto its end.
- 2) The cylinder shall be dropped horizontally onto its sidewall.
- 3) The cylinder shall be dropped horizontally onto a 3.8 x 0.48 cm piece of angle iron with the included angle in the downward position. The cylinder shall land at right angles to and on the heel edge of the angle iron, impacting approximately in the center of the sidewall.

The cylinder is then subject to a minimum of 1,000 cycles, pressurized between 10% of service pressure and service pressure at a rate not exceeding 10 cycles per minute (Figure 1). The minimum dwell time at the 90-100% range of each cycle was not less than 1.2 seconds.

The cylinder was then burst hydrostatically in accordance with DOT-CFFC-10(b)(i) (Figure 2).

TEST RESULTS:

The cylinder showed no signs of visually observable damage, distortion, or leakage after completion of pressure cycling.

The cylinder ruptured at a recorded pressure of 589.1 bar (8,544 psi).

TEST REPORT

DOT-CFFC-10 (c) DROP TEST

DYN-H3220 Drop Test
1,000 pressure cycles

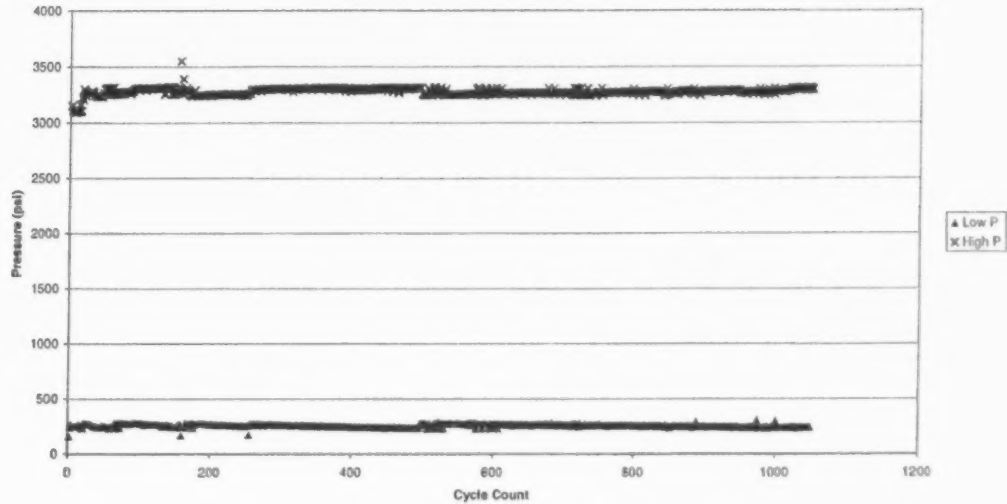


Figure 1: Dynetek H3220, Plot of 1,000 pressure cycles

DYN-H3220 Drop Burst

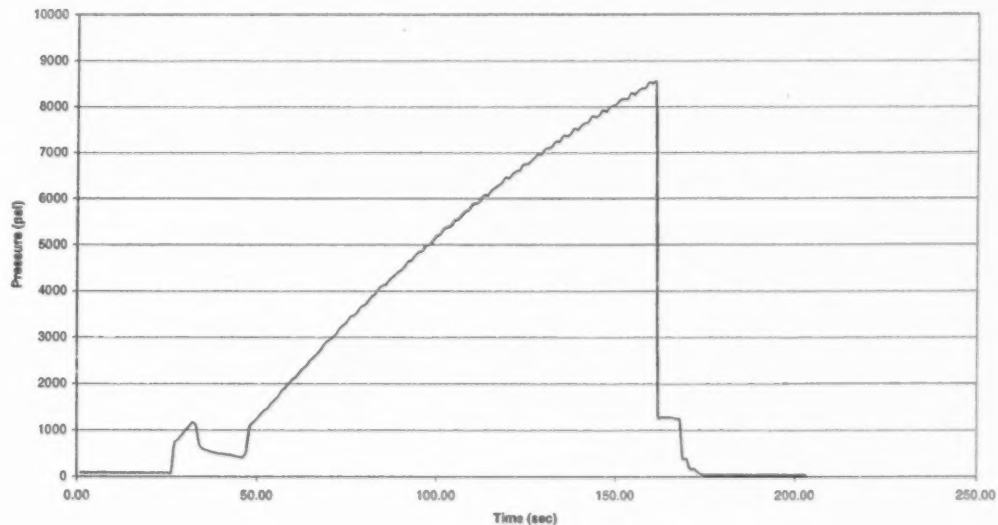


Figure 2: Dynetek H3220, Plot of burst pressure

TEST REPORT

DOT-CFFC-10 (c) DROP TEST

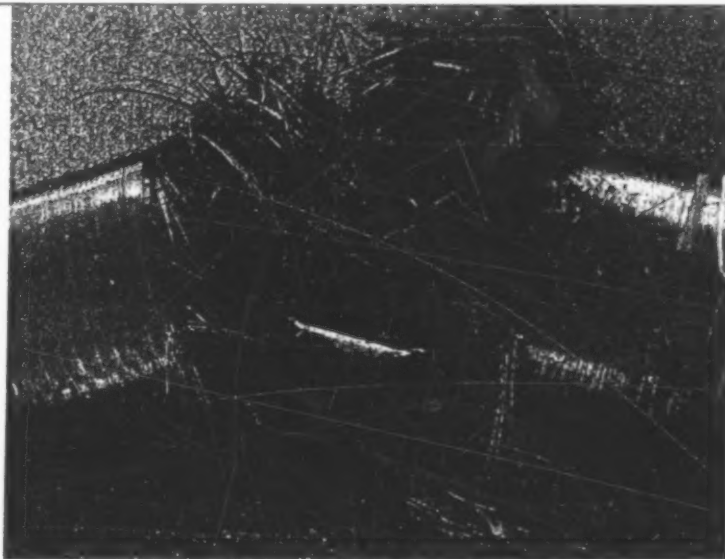
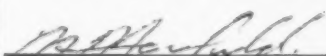


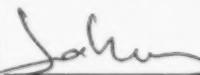
Figure 3: Dynetek 3220, Image after rupture

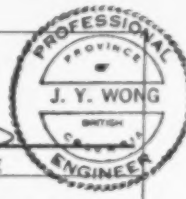
Tested By:


Norbert Neufeld, A.Sc.T.

Date: August 12, 2002

Approved By:


Joe Y. Wong, P.Eng



TEST REPORT

CSA B339-01 (9.13.3) CYCLING TESTS

Prepared for: Dynetek Industries Ltd.

Project Number: 12670-36

Manufacturer: Dynetek Industries Ltd.
Part Type: W150TDG223G5N
Serial Number: H3161
Part Data: Type-3 Cylinder, 223 bar (3240 psi) Service Pressure

TEST CONDUCTED:

The following test was conducted in accordance with:

- CSA B339-01, Clause 9.13.3 (a): Ambient Temperature Cycling Test

TEST PROCEDURE:

Cycling tests shall be performed hydrostatically at a rate not exceeding 4 cycles /min from approximately 0 kPa to the specified pressure. Testing shall be as follows:

- a) Ambient temperature cycling test. One cylinder shall be cycling tested at ambient temperature with out failure
 - (i) to service pressure to 10 000 cycles (Figure 1), and
 - (ii) to 1.11 times test pressure for 30 cycles (Figure 2)
- b) The cylinder shall then be tested hydrostatically to destruction and the burst pressure recorded (Figure 3).

TEST RESULTS:

The cylinder showed no signs of visually observable damage, distortion, or leakage after completion of pressure cycling.

The cylinder leaked at a recorded pressure of 689.96 bar (10,007 psi).

TEST REPORT

CSA B339-01 (9.13.3) CYCLING TESTS

DYN-H3161 Ambient Cycling Test
10,000 cycles High/Low Pressure Plot

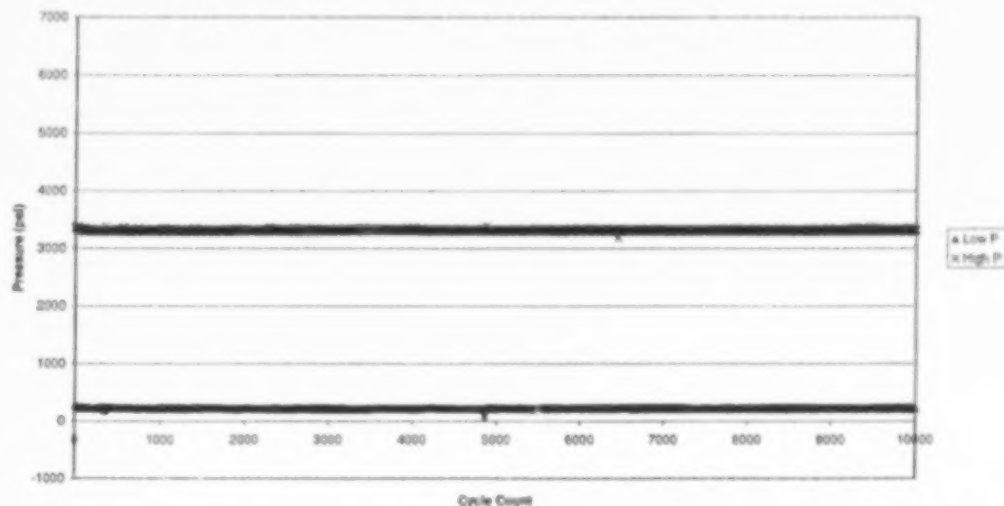


Figure 1: Dynetek H3161, Plot of High and Low pressure values for 10,000 cycles

DYN-H3161 Ambient Cycling Test
30 cycles High/Low Pressure Plot

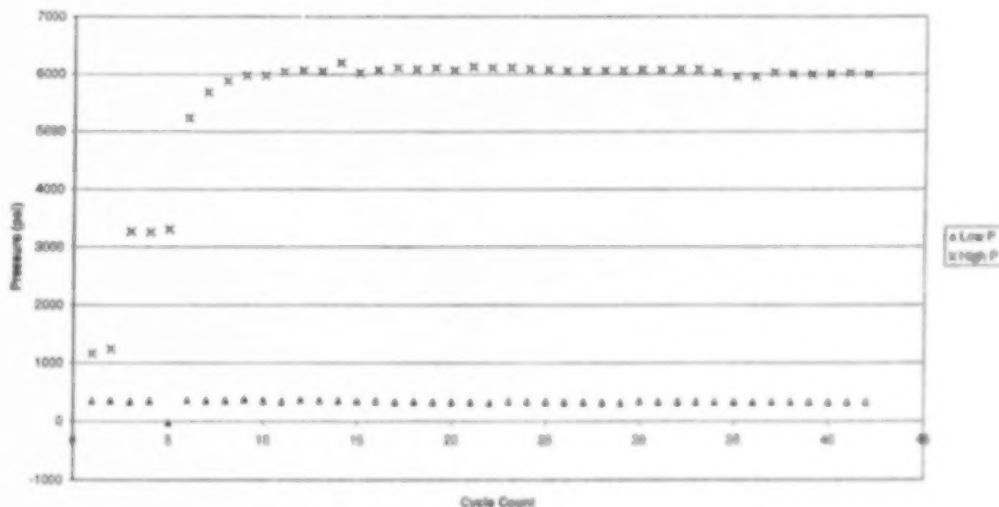


Figure 2: Dynetek H3161, Plot of High and Low pressure values for 30 cycles

CSA B339-01 (9.13.3) CYCLING TESTS

DYN-H3161 Ambient Burst

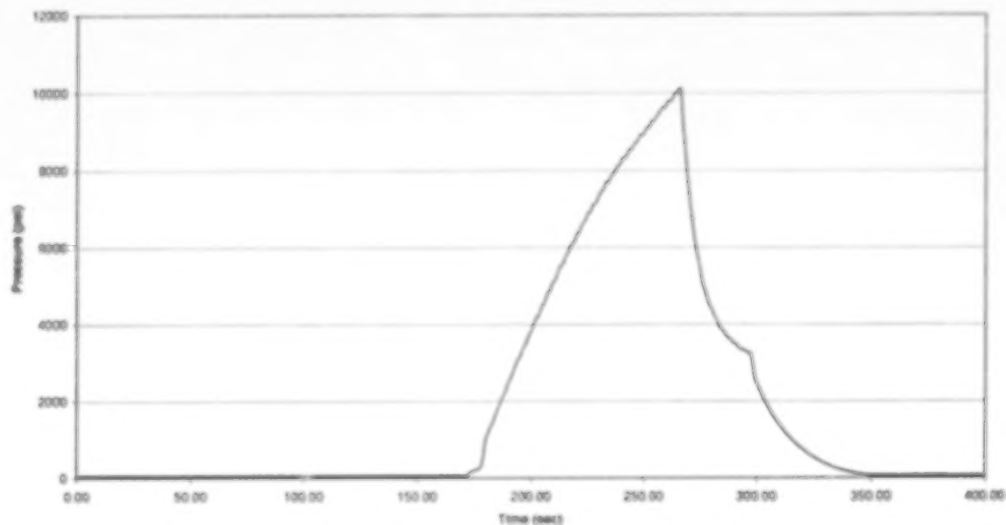


Figure 3: Dynetek H3161, Plot of burst pressure



Figure 4: Dynetek H3161, Cylinder during leaking

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CSA B339-01 (9.13.3) CYCLING TESTS

Tested By:

Approved By:


Norbert Neufeld, A.Sc.T.


Joe Y. Wong, P.Eng



Date: August 13, 2002

APPENDIX B

**DYNETEK CONTAINER UNIT
STRUCTURAL ANALYSIS**



Number: 02-03
Subject: FE Analysis of Mobile Hydrogen Storage System Frame
Author: Matthew Harper
Project: Customer Projects: Hydrogen Storage
Date: June 28, 2002

1. Objective

To determine whether the MHSS frame (GH Part # 001638) is strong enough to sustain impact loads.

2. Methodology

First, the production Pro/Engineer model was modified to ensure continuity between parts, and to simplify the model so as to reduce analysis time. This assembly was then imported into DesignSpace FE Analysis software. The results were captured as .jpg images showing the more highly-stressed areas; those images are presented below. Three separate load cases were analyzed: Front and side impacts, and vertical load. The masses of the cylinders and frame were the only applied loads. Then, the stresses induced in the structure were evaluated to make sure they did not exceed the safety factor specified by DOT standards (see §3).

3. Assumptions and Data Sources

Requirements for the strength of structures in gas transportation systems are outlined in US DOT Hazardous Materials Regulations and Procedures Codes. Chapter 1, Subchapter C, Part 178.255-11 states that frames for transportable tanks shall "be designed with a safety factor of four, and built to withstand loadings in either direction of two times the weight of the tanks and attachments", or an effective safety factor of 8 on a 1-g load.

4. Results

The results of the analysis are shown in Figures 1 through 6, below. It is important to note that, when quantifying the maximum stresses in a particular member, it is necessary to discount localized stress concentrations found in some of the sharp corners. The magnitude of these concentrations is exaggerated by the FE model for two reasons. First, in the actual model, there are thick weld beads holding the member together. These have the effect of distributing the load, but are difficult to model quantitatively. Second, the stress concentrations are higher due to the linear behaviour of the finite element solver. In a real part, the material would deform and thus spread the load over a greater area. Linear FEA, however, does not take account of changes in part geometry, and thus the force-distributing characteristic of these deformations are not taken into account.

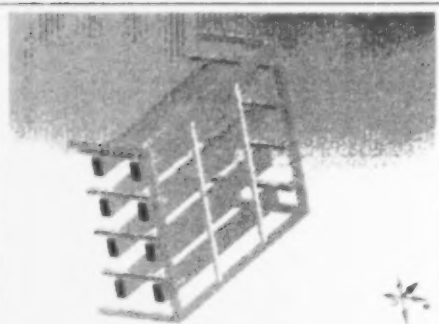


Figure 1: Meshed FE Model

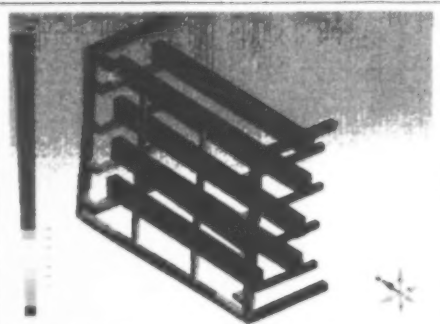


Figure 2: Model showing von-Mises stresses

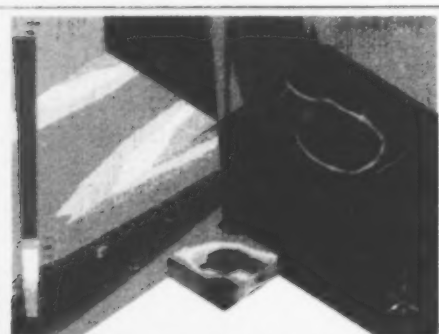


Figure 3: Stresses in corner and mounting lug

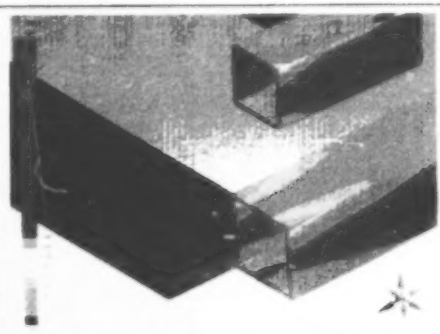


Figure 4: Corner beams w/ post removed for clarity



Figure 5: Stress concentrations



Figure 6: Stresses induced by side impact

4. Results (Continued)

The models showed that the highest stresses on the structure were for the front impact case, with moderate stresses in the side impact and vertical load cases. Graphical representations of these results are shown in figures 1-5. Maximum combined (von Mises) stresses were found to be in the region of 8 kpsi, neglecting local stress concentrations as noted above. The maximum horizontal deflection at the top of the assembly for the applied 1-g load was 0.165". Stresses for the side impact case (figure 6) were approximately 2 kpsi (again neglecting localized stress concentrations). As these figures are all more than a factor of 8 smaller than the material's ultimate tensile strength (80 kpsi for 304L stainless steel), it can be concluded that the frame is strong enough for the intended application.

The stresses in the mounting lugs were found to be quite high. However, the lug is being compressed against one of the main support members, which makes a failure unlikely. Also, the model does not account for the distributing effect that the bolt pre-load will have on transferring reaction forces. Thus, yielding of the lug is not seen as a likely failure mode.

5. Conclusion

It has been concluded that the structure is sound, and meets the DOT specification for support frames for transportable tanks.

6. References

All relevant documents have been stored in the following directory:
G:\Technical Development\Technical Library\Mechanical Engineering Investigation
Reports\Supporting Documents

- 001638 Front Impact.dsdh
- 001638 Side and Vertical Impact.dsdh
- 001638 side impact detail.jpg
- 001638 corner post removed.jpg
- 001638 corners and lugs.jpg
- 001638 corners.jpg
- 001638 mesh.jpg
- 001638 overall stress.jpg

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